

Jezero Crater Watershed, Isidis Basin, Sulfate Deposits and Syrtis Major: A Compelling Exploration Zone for Human Exploration

#1034

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Noachian Plains Exploration Zone

19° N

18° N

17° N

Science ROI:
Western Watershed

Science ROI:
Northern Watershed

Science ROI:
Olivine – Carbonate
Ancient Crust

Science/Resource ROI:
Sulfate & Carbonate

Syrtis
Major

Science ROI:
Jezero Deltas

2

3

4

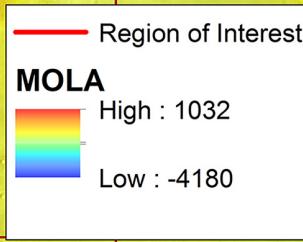
Surface Field Station

17.747 N 77.037 E
-2000 m elevation

Science/Resource ROI:
Carbonate & Serpentine

Isidis
Planitia

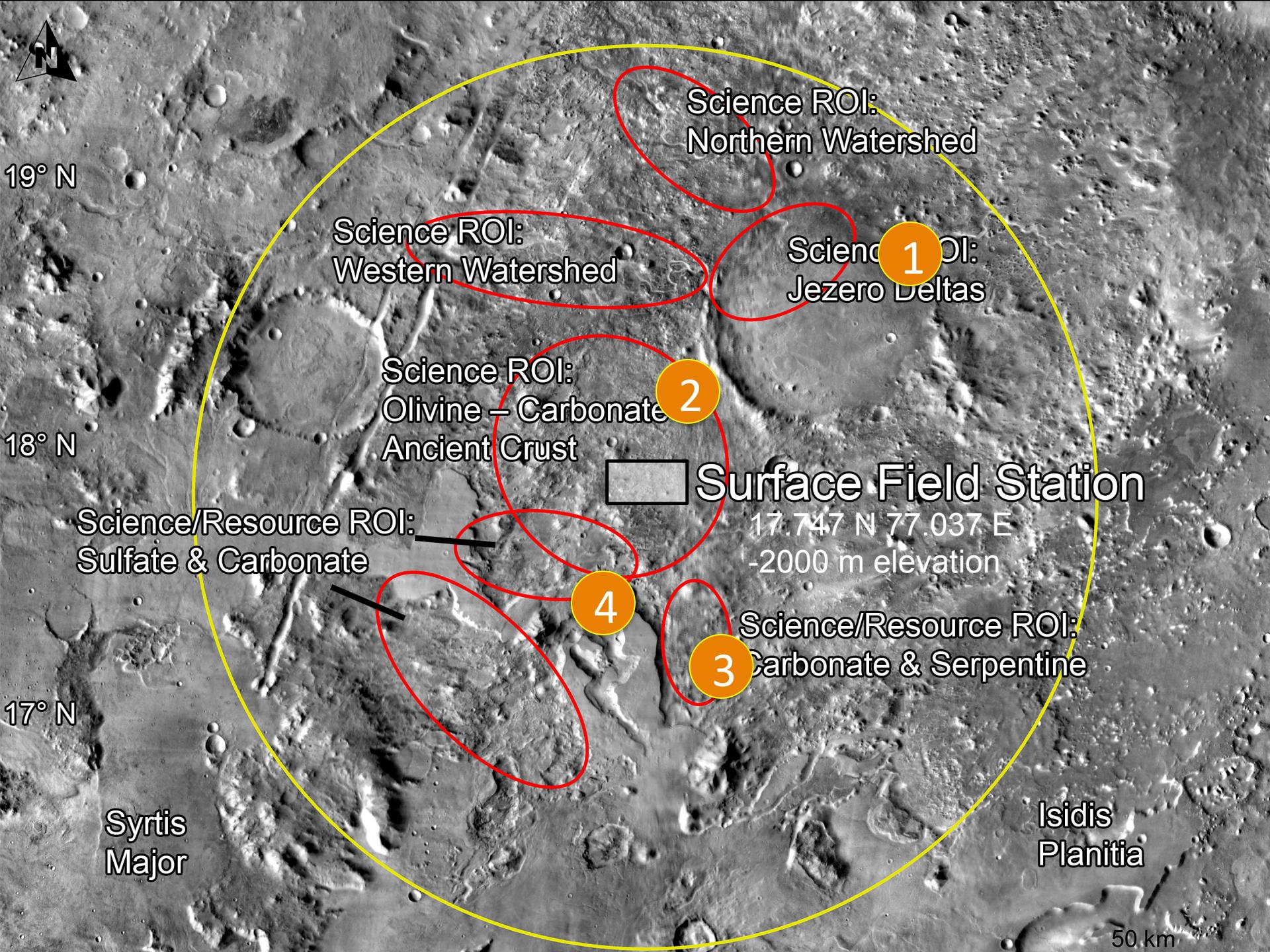
50 km



76° E

77° E

78° E



Compelling Mars and Astrobiology Science

- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
 - early crustal: creation or distribution by impact? Phyllosilicate formation
 - carbonate/serpentine: surface alteration or hydrothermal?
 - layered phyllosilicates (Al- over Fe/Mg)
 - sedimentary sulfate formation
- Compelling delta in the Jezero closed basin lake with sedimentary carbonate and Fe/Mg- smectites Deltaic and lacustrine sediment is an excellent site for concentration and preservation of organic matter [Summons et al., 2011].
- A record of aqueous low-T geochemistry preserved in-situ, in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting
- Key stratigraphies from Noachian and Hesperian eras
- Hydrothermal, pedogenic and sedimentary environments
- Multiple igneous units of distinct age

Threshold Science Criteria

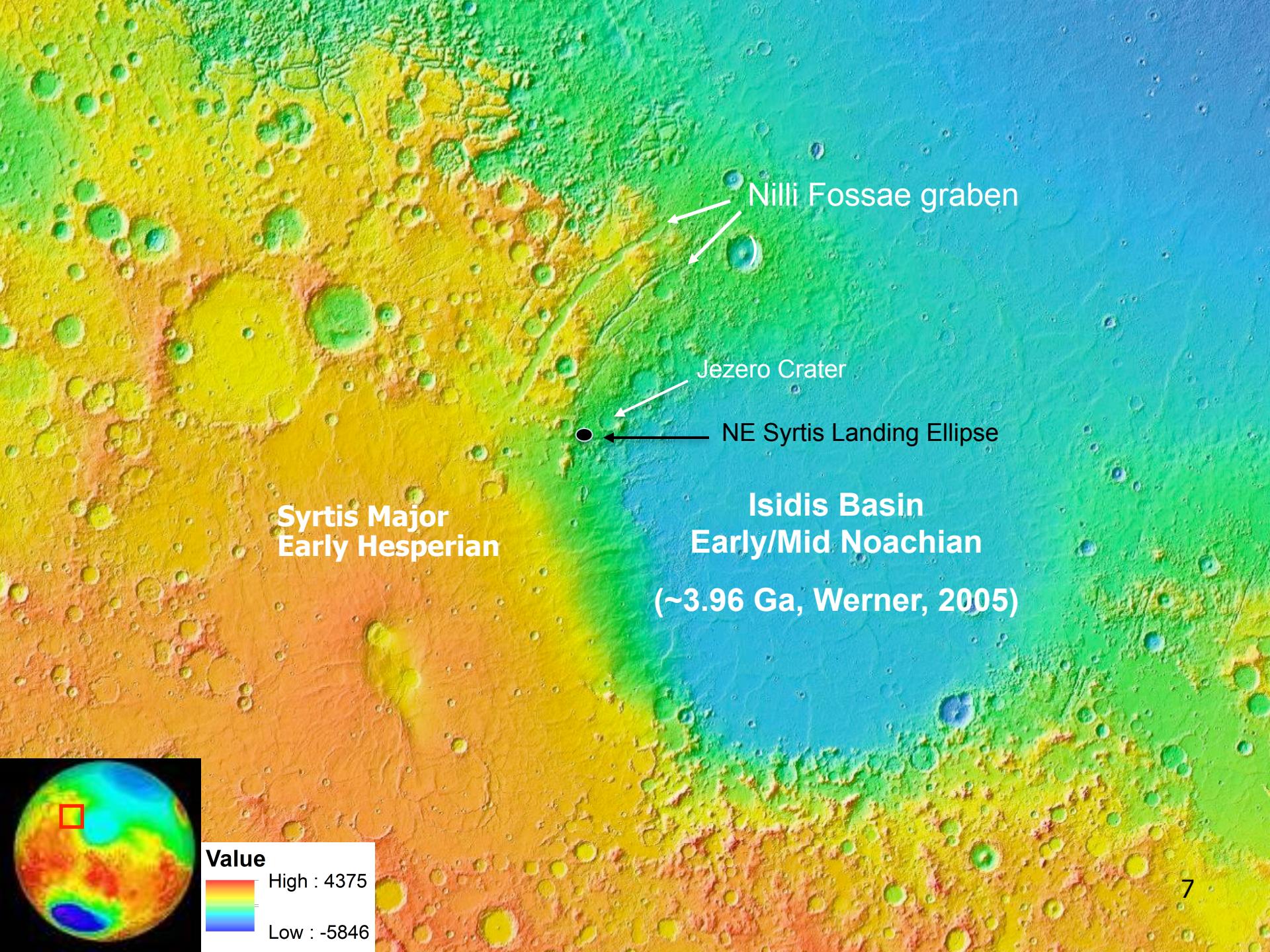
Access to deposits with a high preservation potential for evidence of past habitability and fossil biosignatures		-throughout the EZ are multiple depositional settings including sedimentary, lacustrine, and hydrothermal
Noachian and/or Hesperian rocks in stratigraphic context that have high likelihood of containing trapped atmospheric gasses.		-carbonate, hydrothermal and impact deposits can capture atmospheric gasses
Exposures of at least two crustal units that have regional or global extents, that are suitable for radiometric dating, and that have relative ages that sample a significant range of martian geological time.		Olivine-bearing unit Noachan at the time of the Isidis Impact (major time stratigraphic unit) Syrtis Major volcanics a large and significant Hesperian unit
Access to outcrops with morphological and/or geochemical signatures indicative of aqueous processes or groundwater/mineral interactions.		-Carbonate deposits -Fe-Mg phyllosilicates in sediments and megabreccia -mineralized fracture zones, -unique deposits containing sulfate, kaolinite, serpentine, talc and jarosite
Identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined.		Through many publications the geologic framework and detailed stratigraphy is well defined

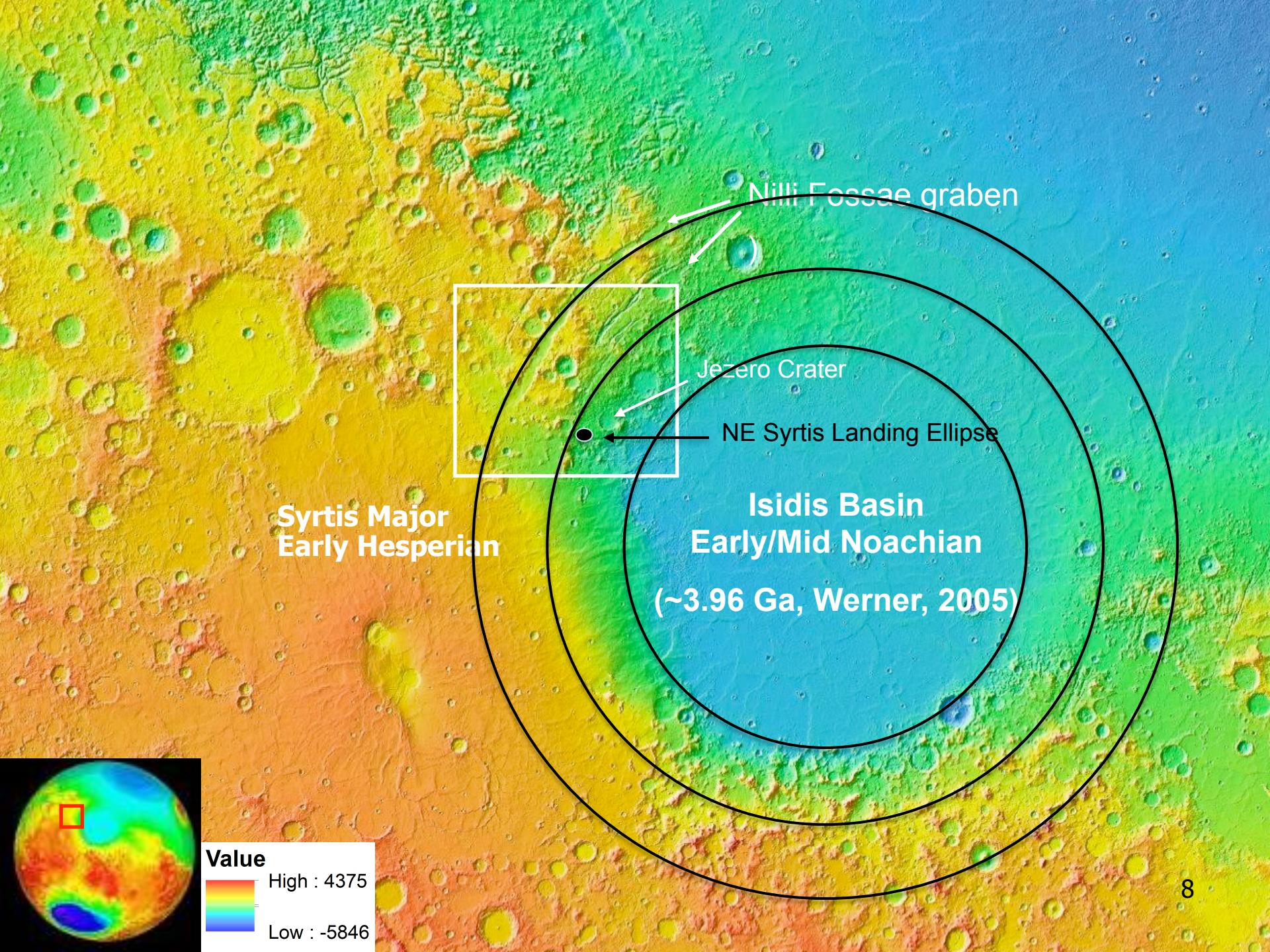
Mars 2020 Landing Site Workshop

Summary of Rubric Analysis

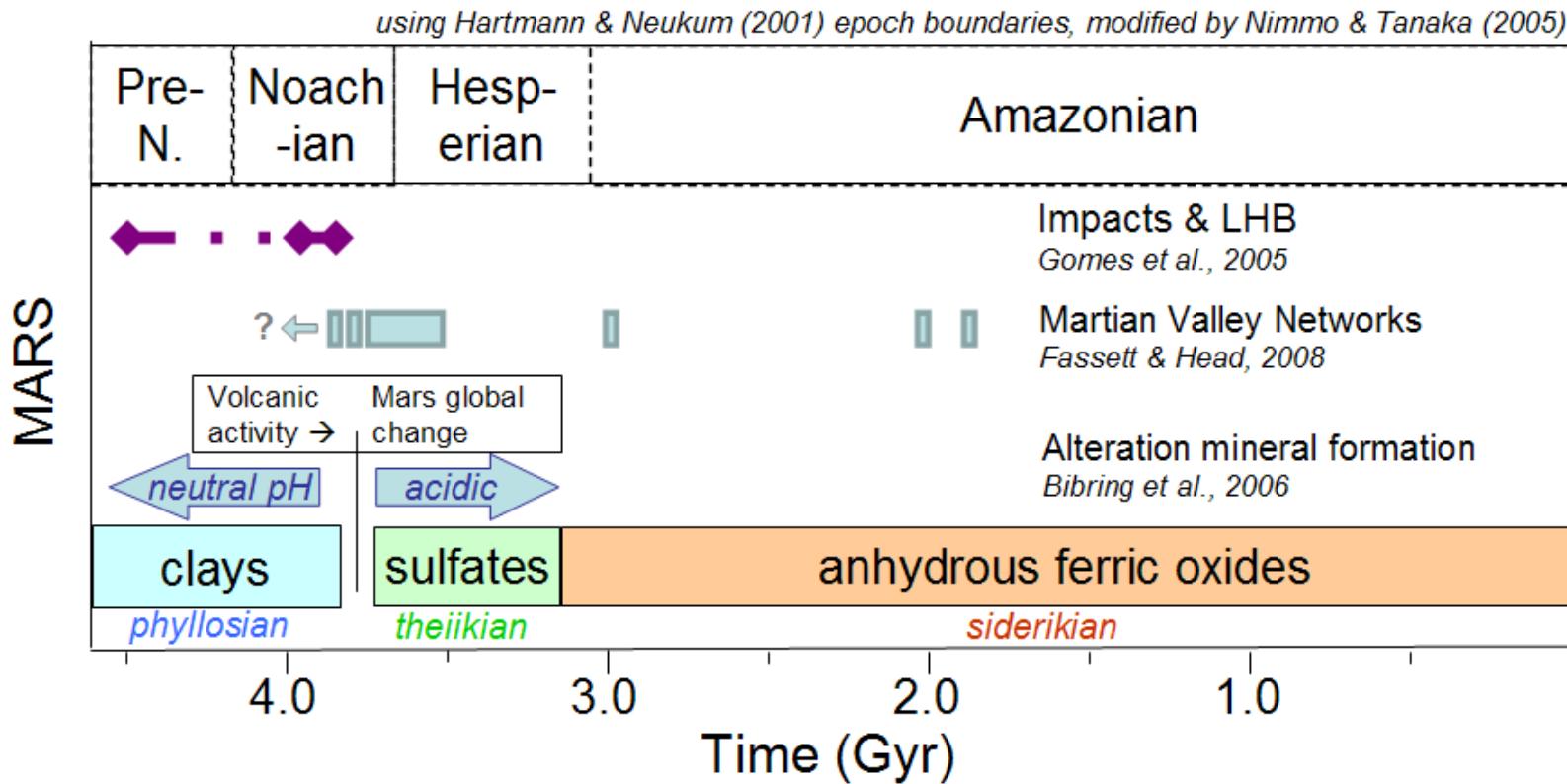


rankings	Site	Landing Site Scientific Selection Criteria											
		CHARACTERIZABLE GEOLOGIC SETTING & HISTORY		ANCIENT HABITABLE ENVIRONMENT		HIGH BIOSIGNATURE PRESERVATION POTENTIAL		ASTROBIOLOGICAL QUALITY OF RETURNED SAMPLES		PETROLOGICAL QUALITY OF RETURNED SAMPLES		AVERAGE	
		mode	average	mode	average	mode	average	mode	average	mode	average	mode	average
1	Jezero	5	4.9	5	4.7	5	4.4	5	4.4	5	4.3	5	4.5
2	Columbia Hills	5	4.7	5	4.3	5	4.3	3	3.8	5	4.1	4.6	4.2
3	NE Syrtis	5	4.7	5	3.8	3	3.3	5	3.8	5	4.8	4.6	4.1
4	Eberswalde	5	5.0	5	4.5	5	4.3	3	3.4	3	3.0	4.2	4.0
5	SW Melas	5	4.5	5	4.1	5	3.9	3	3.6	3	3.1	4.2	3.9
6	Nili Fossae Trough (N)	5	4.4	3	3.4	3	3.2	3	3.4	5	4.7	3.8	3.8
7	Nili Fossae Carbonate	5	4.2	3	3.4	3	3.2	3	3.2	5	4.3	3.8	3.7
8	Mawrth	5	4.3	3	3.7	3	2.9	3	3.4	5	3.9	3.8	3.6
9	Holden Crater	5	4.4	3	3.4	3	3.2	3	3.2	3	3.4	3.4	3.5
10	McLaughlin	3	3.6	3	3.9	3	3.0	3	3.5	3	3.5	3	3.5
11	Hypanis	3	3.8	3	3.6	3	3.1	3	3.0	3	2.8	3	3.2
12	Nili Fossae Trough (S)	3	3.8	3	2.9	3	2.6	3	2.9	3	3.9	3	3.2
13	Ladon Valles	3	3.8	3	3.3	3	3.1	3	2.7	3	2.7	3	3.1
14	E. Margaritifer	3	3.7	3	3.1	3	3.5	3	2.7	3	2.7	3	3.1
15	Coprates Chasma	5	4.1	3	2.7	3	2.3	3	2.5	3	3.7	3.4	3.1
16	Oyama Crater	3	3.3	3	3.2	3	2.8	3	2.7	3	3.1	3	3.0
17	Eridania	3	3.2	3	2.8	3	2.5	3	2.3	3	2.4	3	2.6
18	Nili Patera	5	4.6	3	2.4	3	2.5	1	1.4	3	2.2	3	2.6
19	Oxia Planum	3	3.0	3	2.4	1	2.1	1	2.1	3	2.7	2.2	2.5
20	Sabrina/Magong Crater	3	3.1	3	3.0	3	2.2	1	1.8	1	2.0	2.2	2.4
21	Hadriacus Palus	3	3.2	3	2.5	1	1.5	1	1.6	3	2.8	2.2	2.3





Well Understood, Time-Ordered Stratigraphy

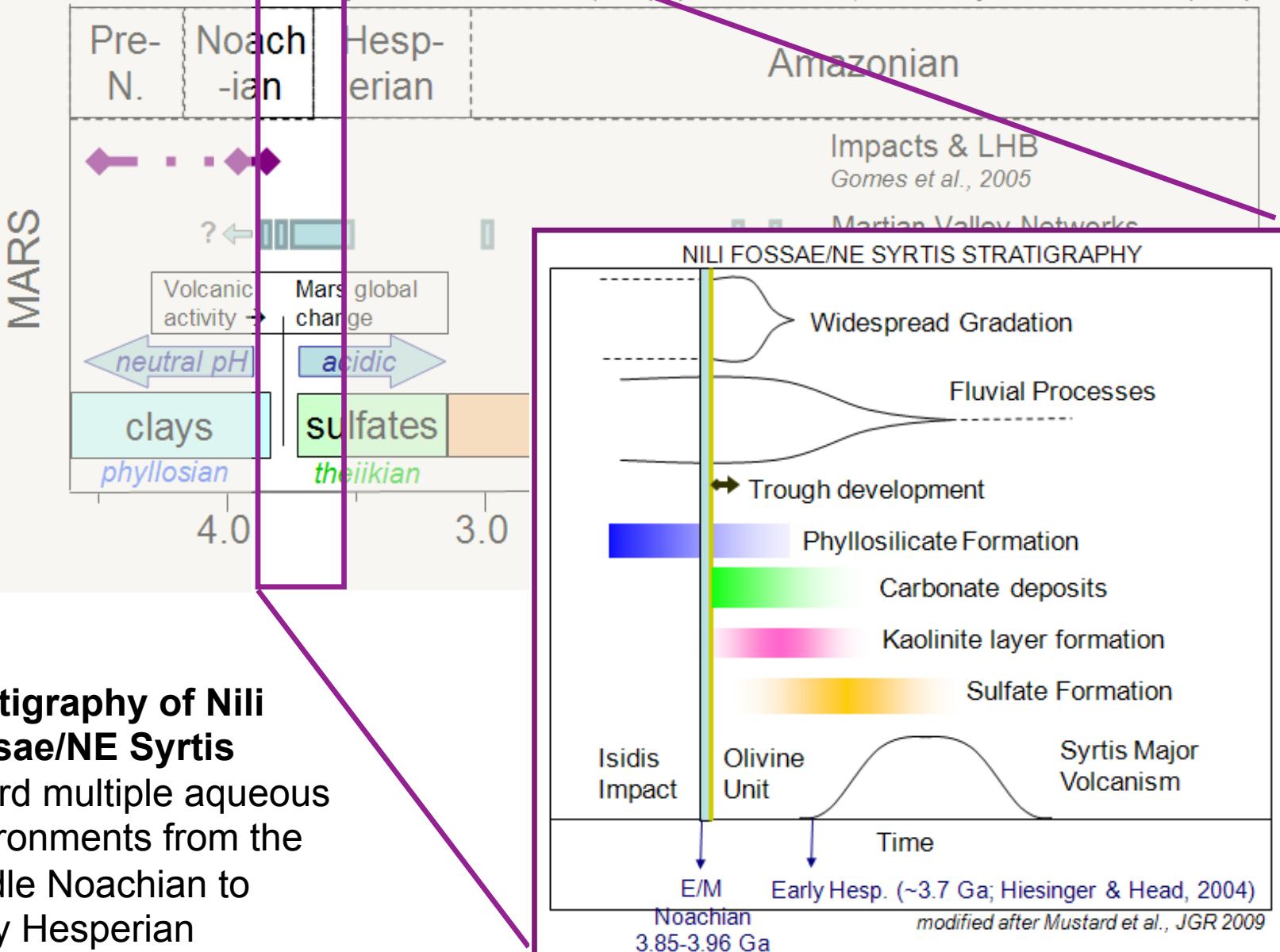


Stratigraphy of Nili Fossae/NE Syrtis

record multiple aqueous environments from the Middle Noachian to Early Hesperian

Well Understood, Time-Ordered Stratigraphy

using Hartmann & Neukum (2001) epoch boundaries, modified by Nimmo & Tanaka (2005)



Testable Hypotheses

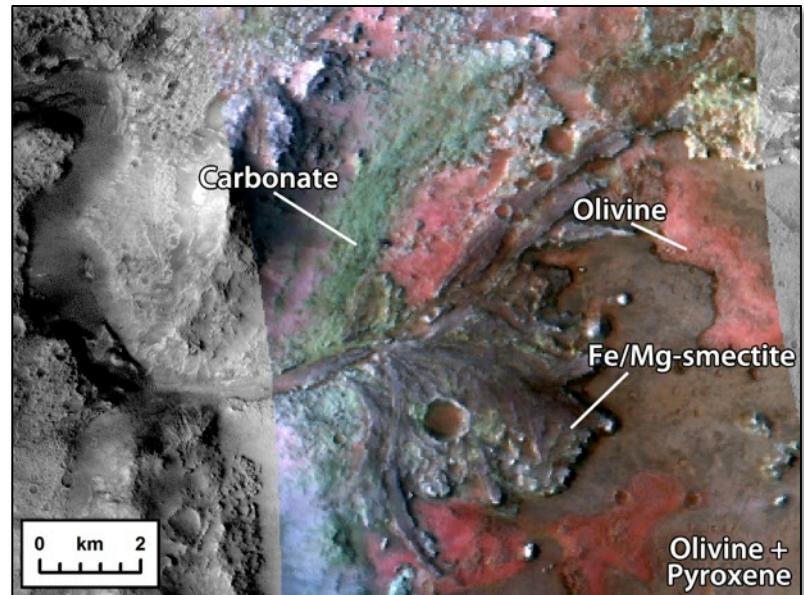
Olivine-bearing regional unit	<ul style="list-style-type: none">• Ultramafic volcanic emplaced post-Isidis• Ultramafic impact melt from Isidis that tapped the mantle
Olivine-Magnesite Mineral Assemblage	<ul style="list-style-type: none">• Near-surface weathering• Serpentinizing hydrothermal systems (Trace Gasses)• Aqueous alteration in a metamorphic setting• Sedimentary/lacustrine deposits within ultramafic catchments
Megabreccia with phyllosilicate and unaltered igneous outcrops	<ul style="list-style-type: none">• Altered with phyllosilicate: Low-T subsurface vs buried sediments• Unaltered (igneous)<ul style="list-style-type: none">• Remnants of Mars primary crust• Noachian-aged low-Ca pyroxene lavas
Layered kaolinite-bearing capping stratigraphy:	<ul style="list-style-type: none">• Extensive leaching during a period of vertically integrated water cycle• Acid leaching and snow melt
Erosionally resistant ridges	<ul style="list-style-type: none">• Fracture zones mineralized with hydrothermal precipitates• Breccia Dikes
Hesperian-aged Sulfate stratigraphy	<ul style="list-style-type: none">• Sedimentary deposition• Alteration of basalt and Box-work structures with jarosite: Exiting vs. infiltrating acid waters
Syrtis Major Hesperian volcanics	<ul style="list-style-type: none">• Calibration of crater chronology, testing the formation mechanism (chemistry and mineralogy), validating remote sensing

Science ROI-1 Jezero Delta

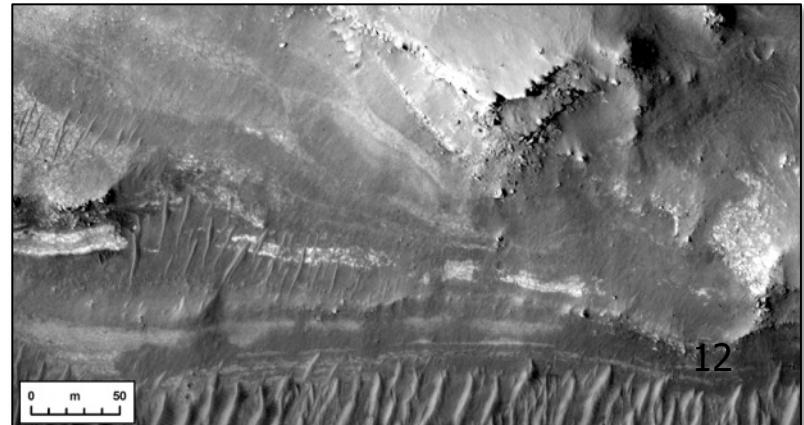
Jezero crater paleolake basin addresses key areas:

- Paleolake with sedimentary carbonate and Fe/Mg-smectites indicates a likely habitable standing body of water with circumneutral pH conditions [*Ehlmann et al., 2008a; Goudge et al., 2015*].
- Deltaic and lacustrine sediment is an excellent site for concentration and preservation of organic matter [*Summons et al., 2011*].

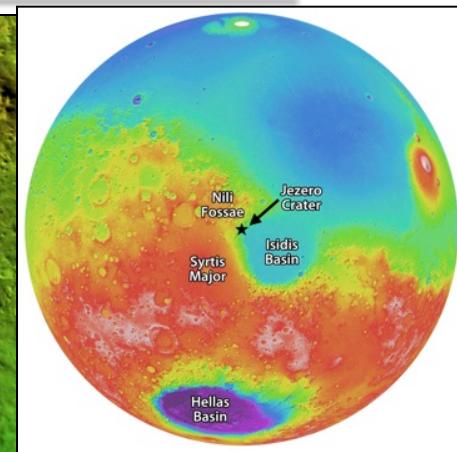
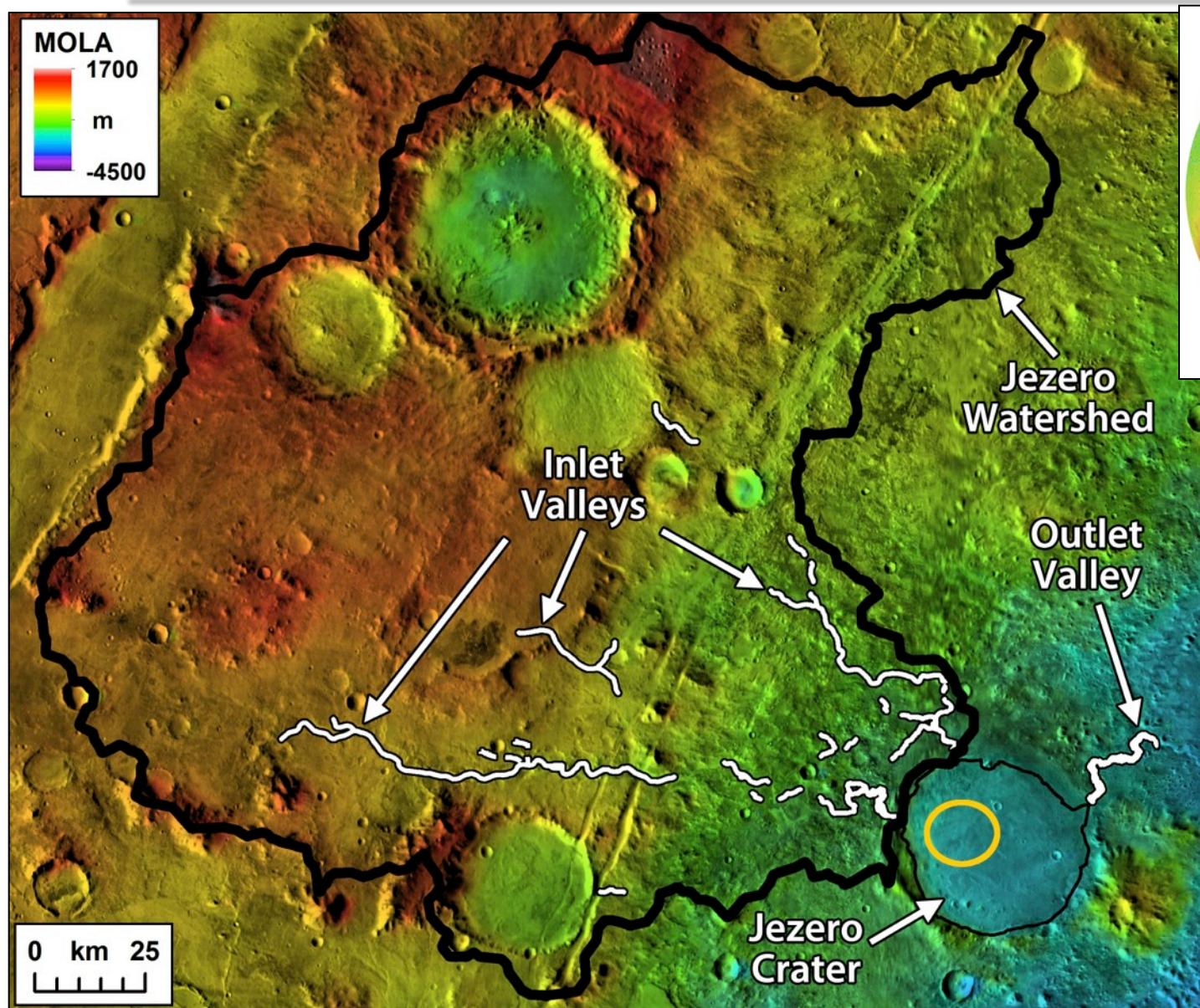
Mineralogic Diversity



Sedimentary Layering

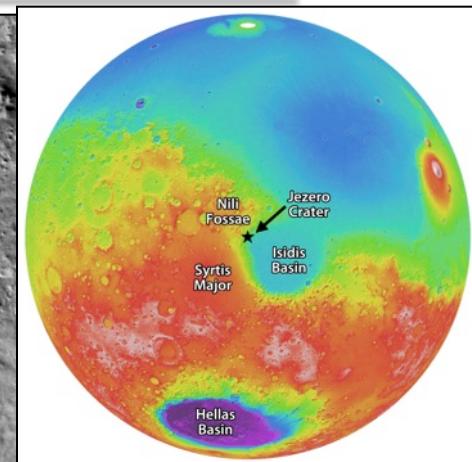
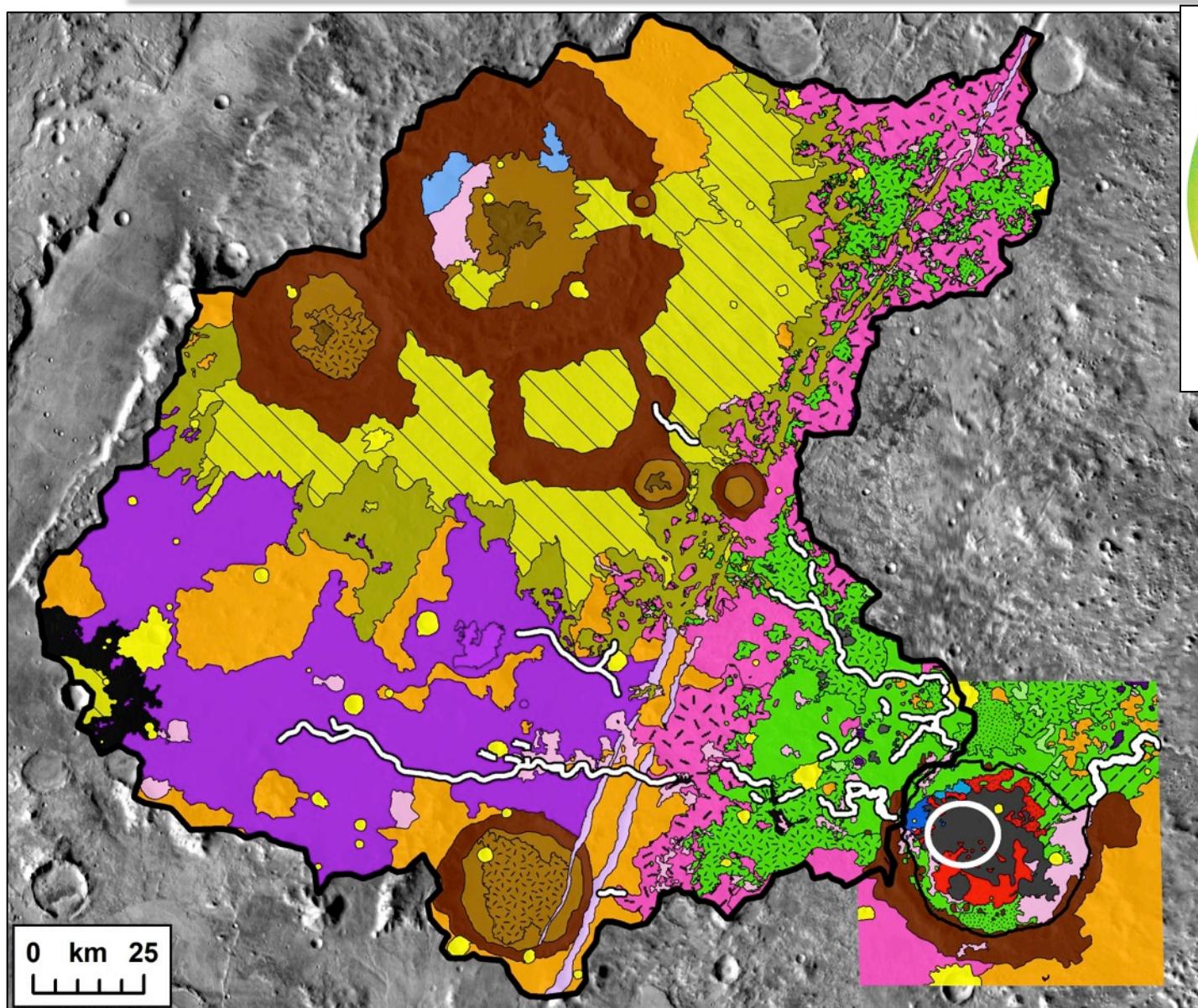


Jezero Watershed



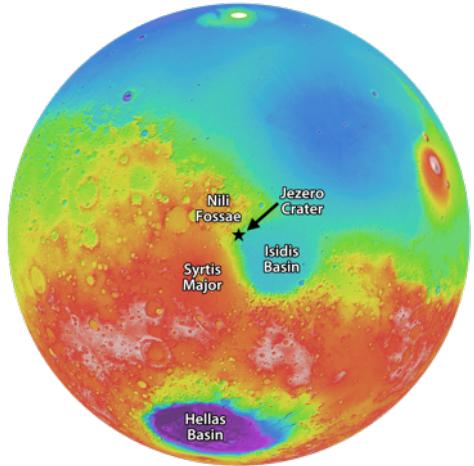
MOLA topography overlaid on THEMIS daytime IR mosaic.

Jezero Watershed Diversity

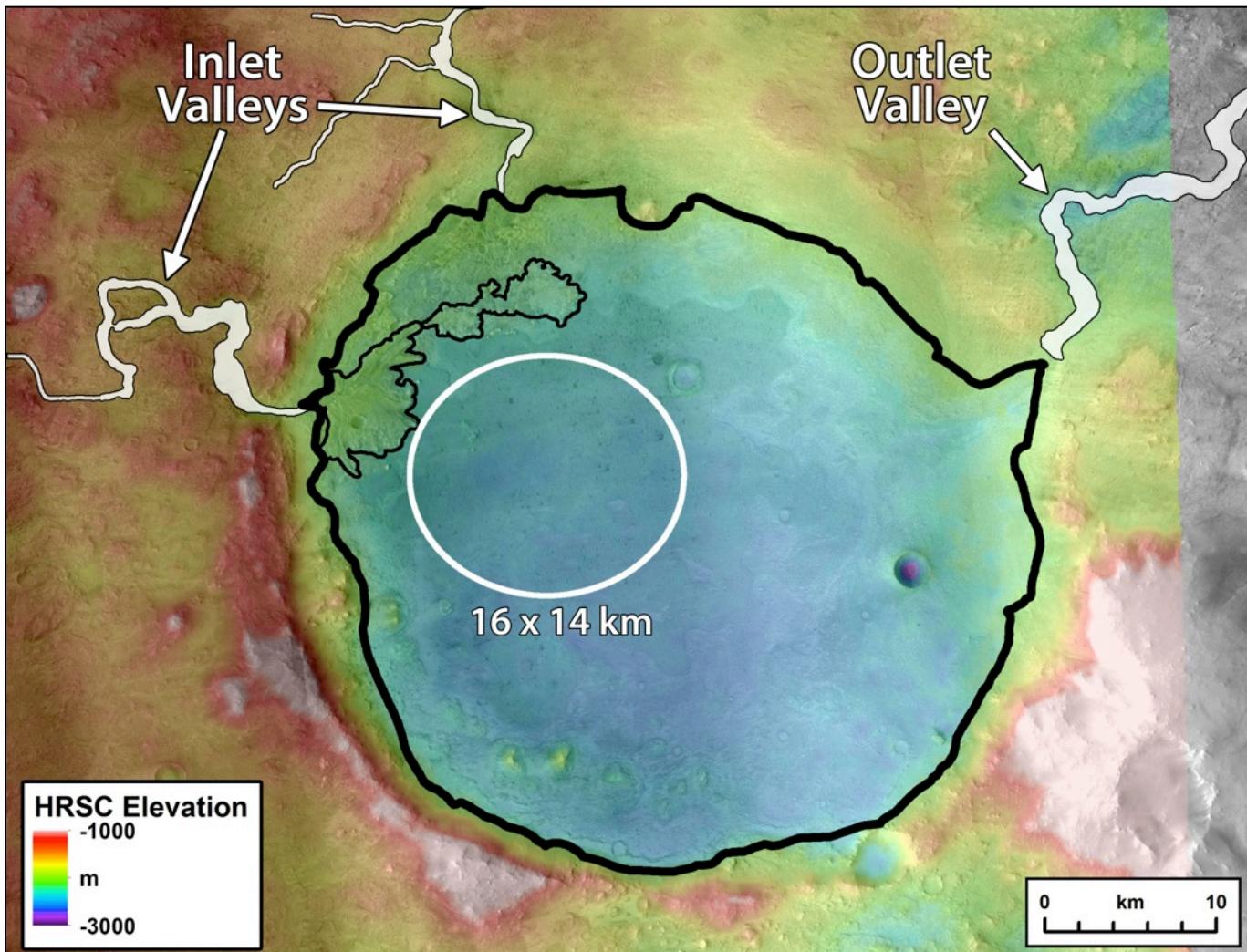


Goudge et al. [2015]

Jezero Crater Paleolake

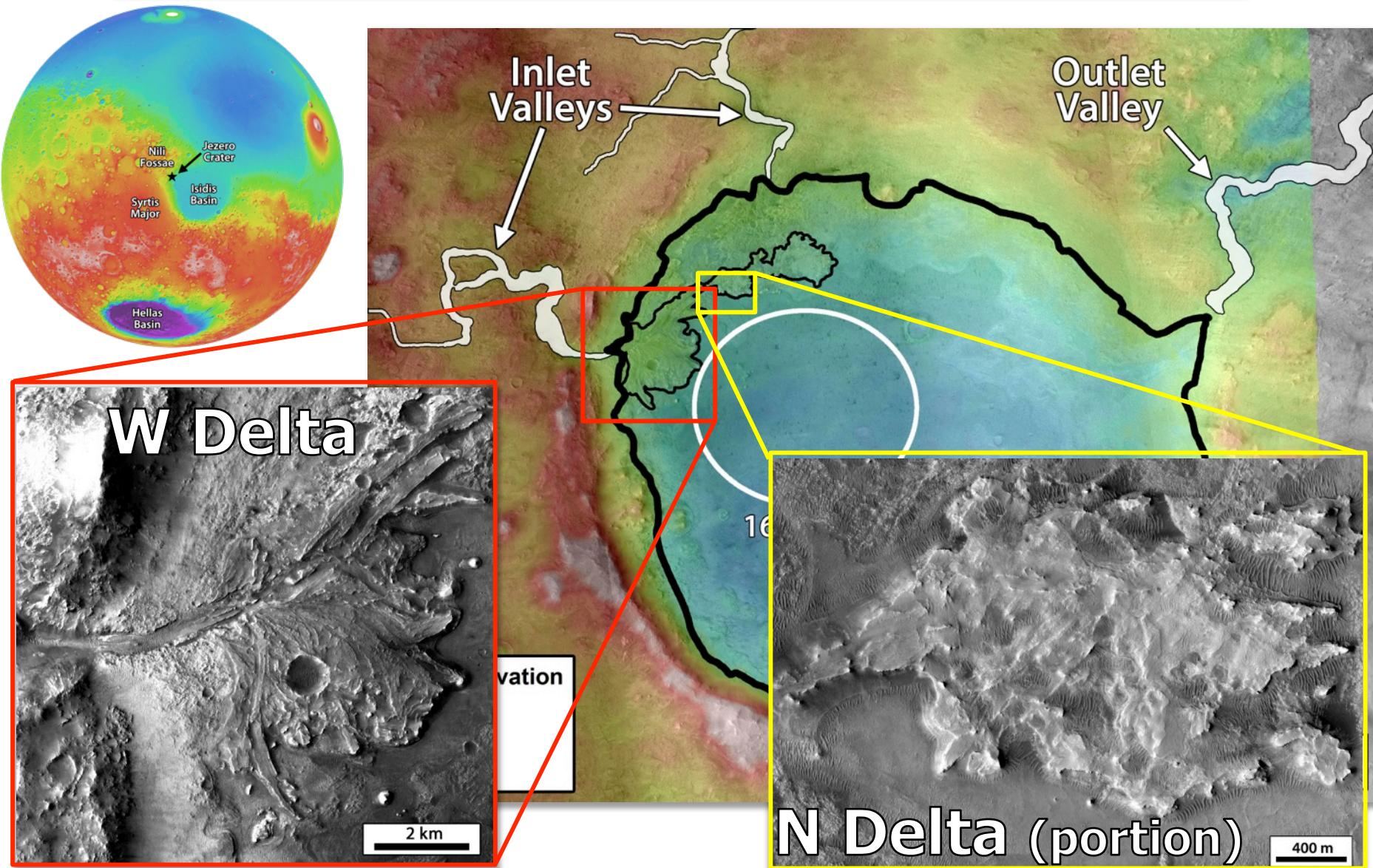


Hydrologically open paleolake with defined minimum lake level. Lake volume is $\sim 250 \text{ km}^3$, similar to Lake Tahoe or Lake Winnipeg [Fassett and Head, 2005; Ehlmann et al., 2008a; Schon et al., 2012; Goudge et al., 2015].

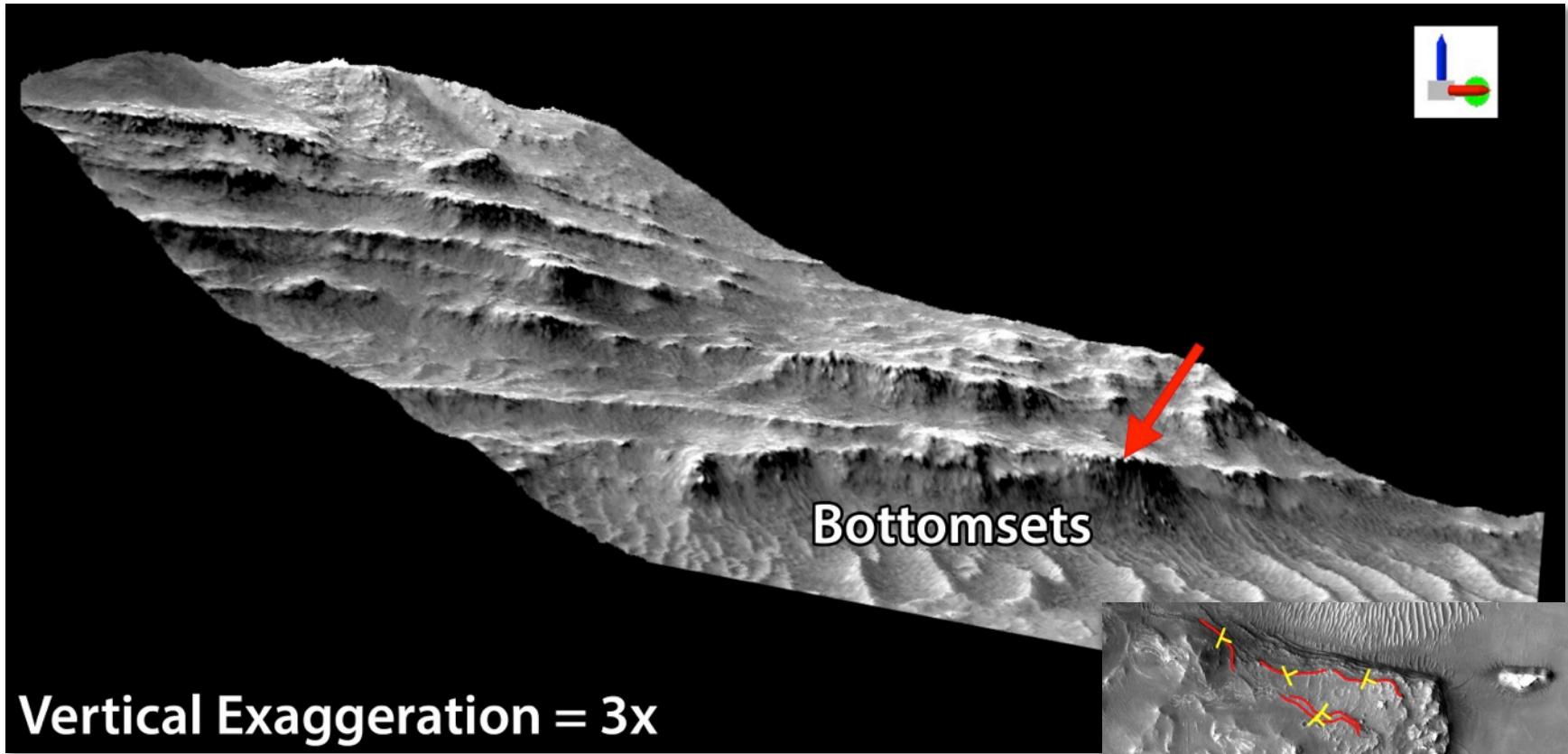


HRSC topography overlaid on CTX mosaic.

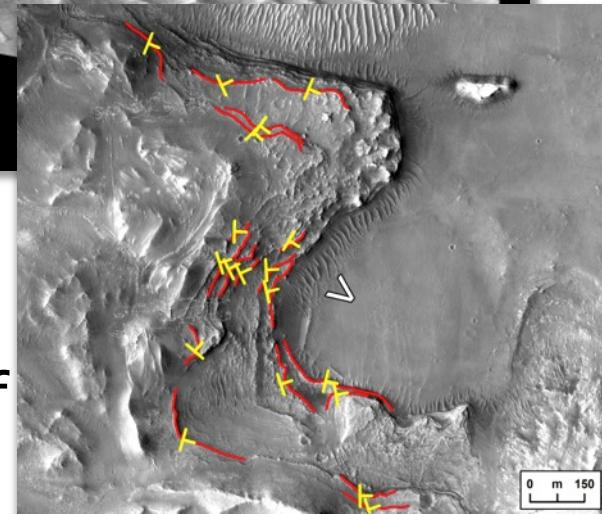
Jezero Delta Deposits



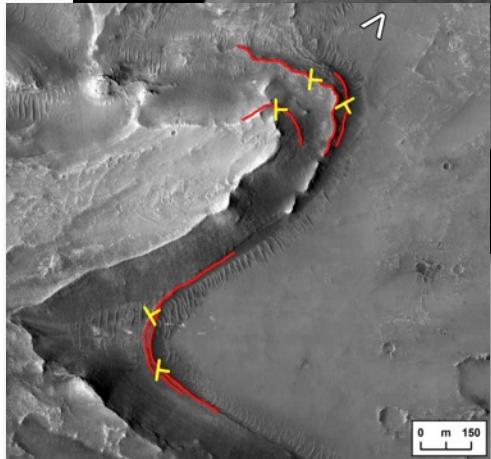
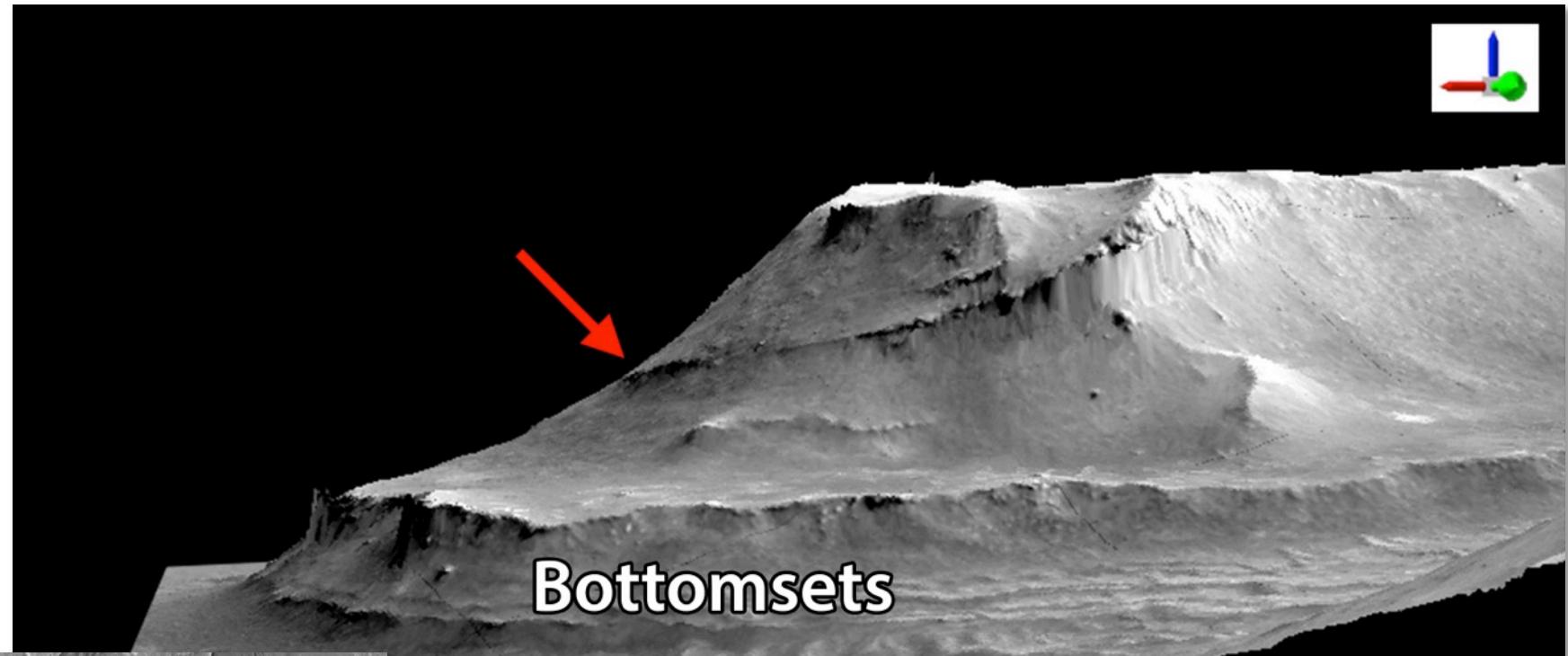
Western Delta Scarp



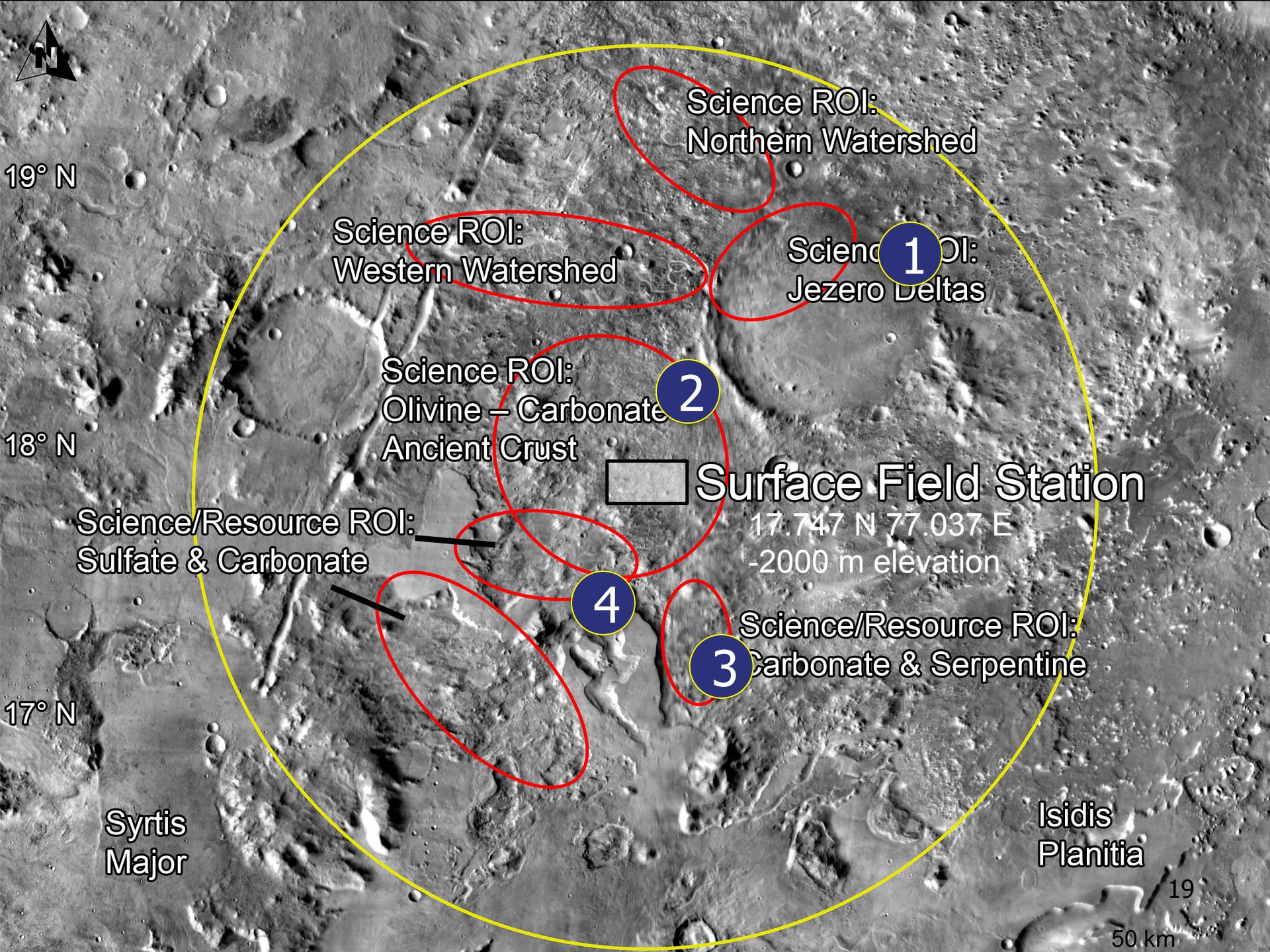
Flat, stratigraphically low units consistent with delta bottomsets. Higher strata exhibit downlapping layer truncations, suggestive of a prograding delta.



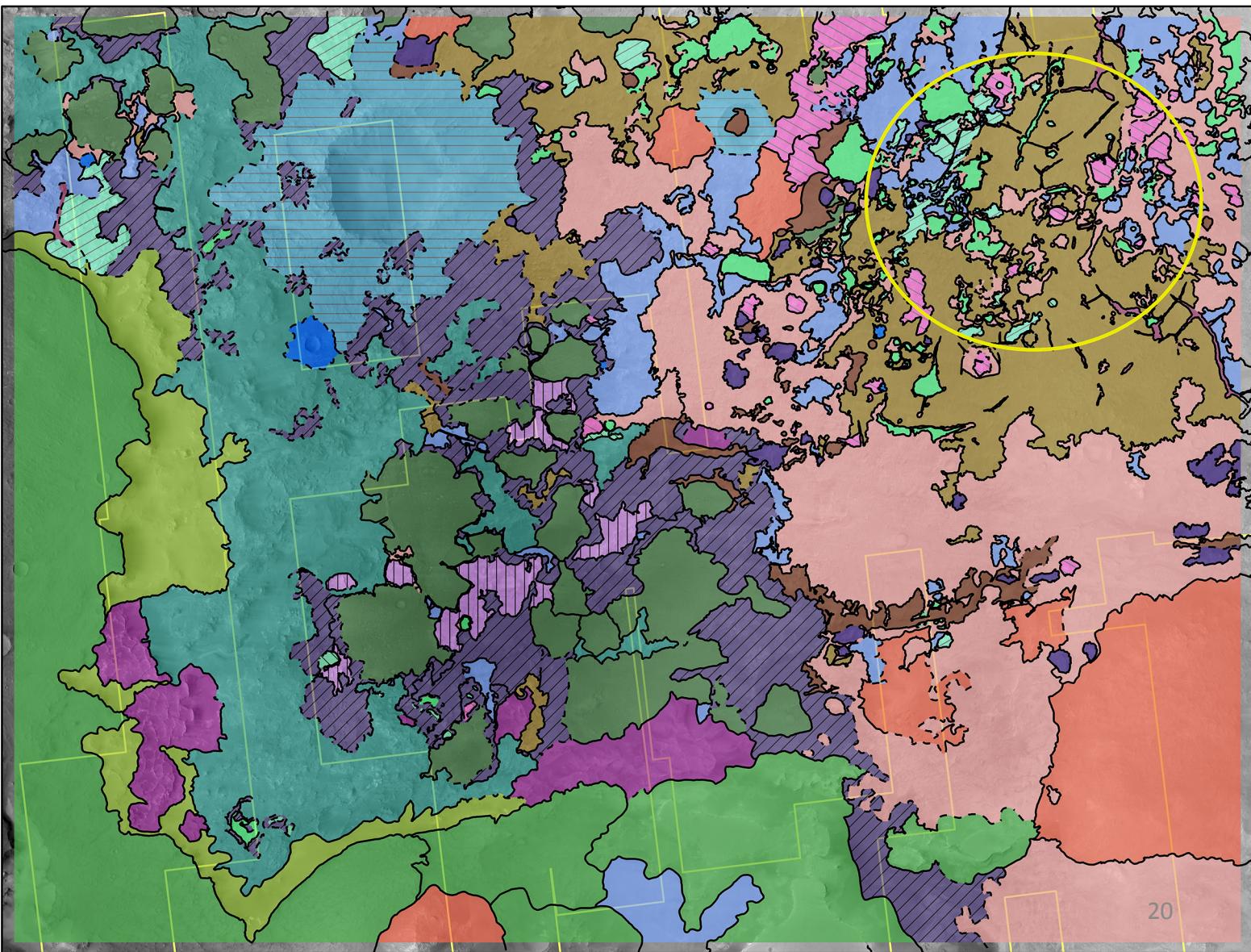
Western Delta Scarp

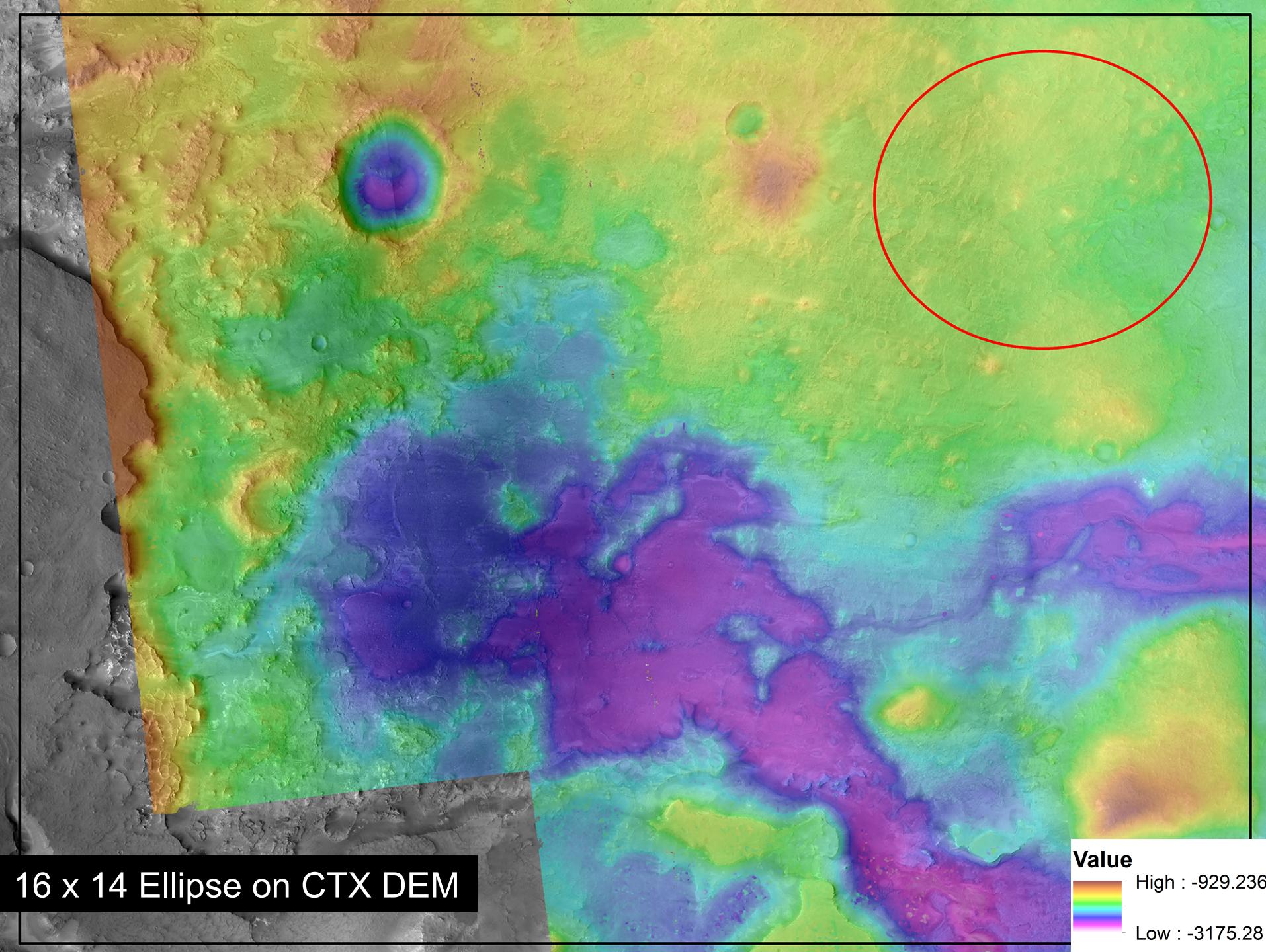


Vertical Exaggeration = 2x



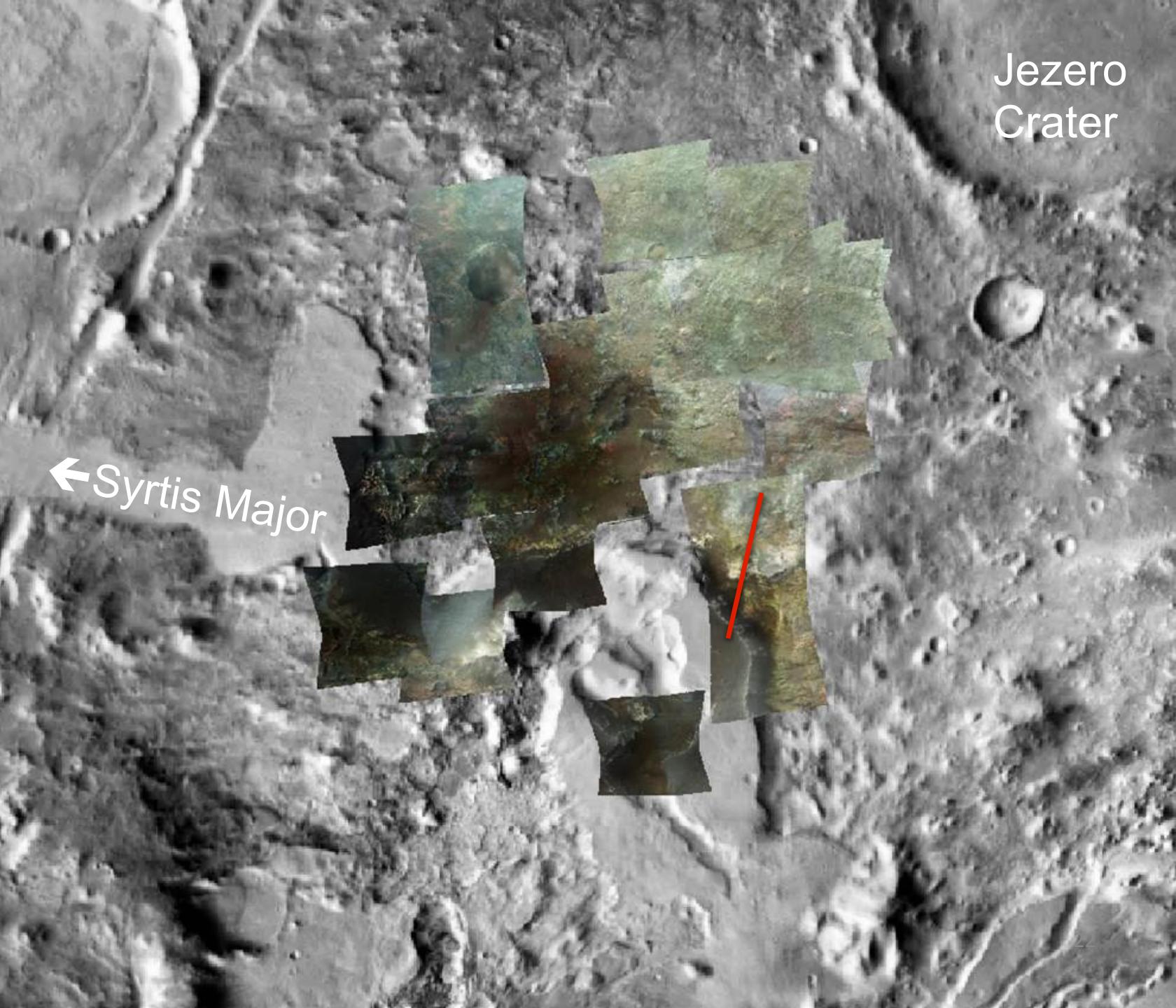
Science ROI 2: Multiple Threshold and Qualifying Criteria





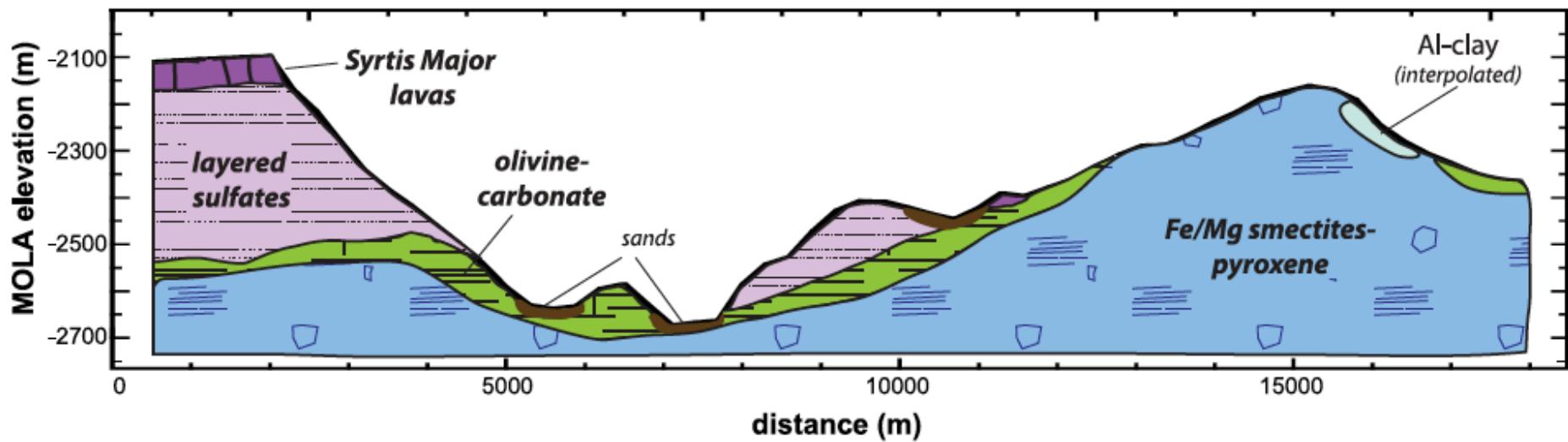
Jezero
Crater

←
Syrtis Major



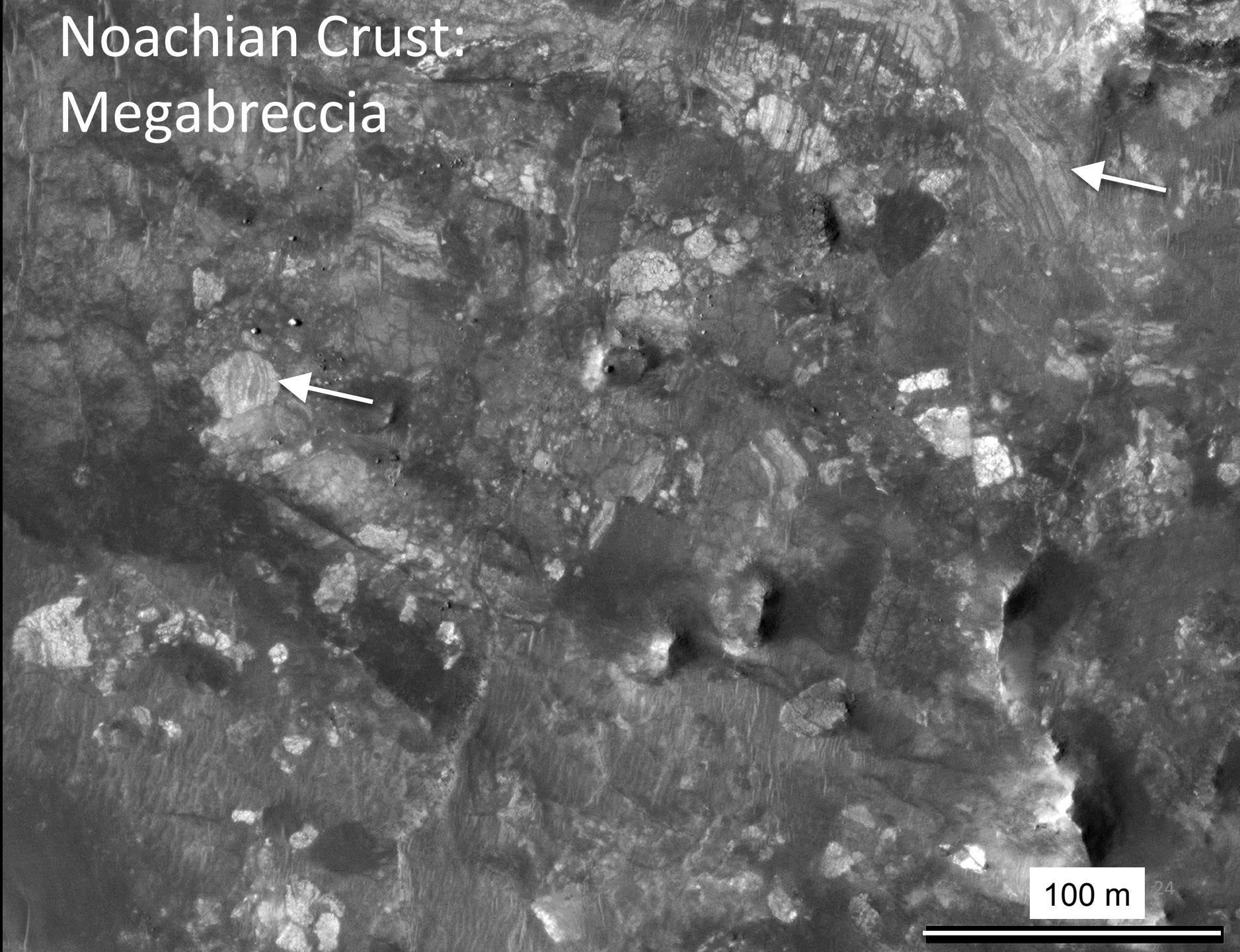
Regional Stratigraphy provides the context for threshold and qualifying criteria

Morphogeologic mapping establishes the local stratigraphy tied to the regional



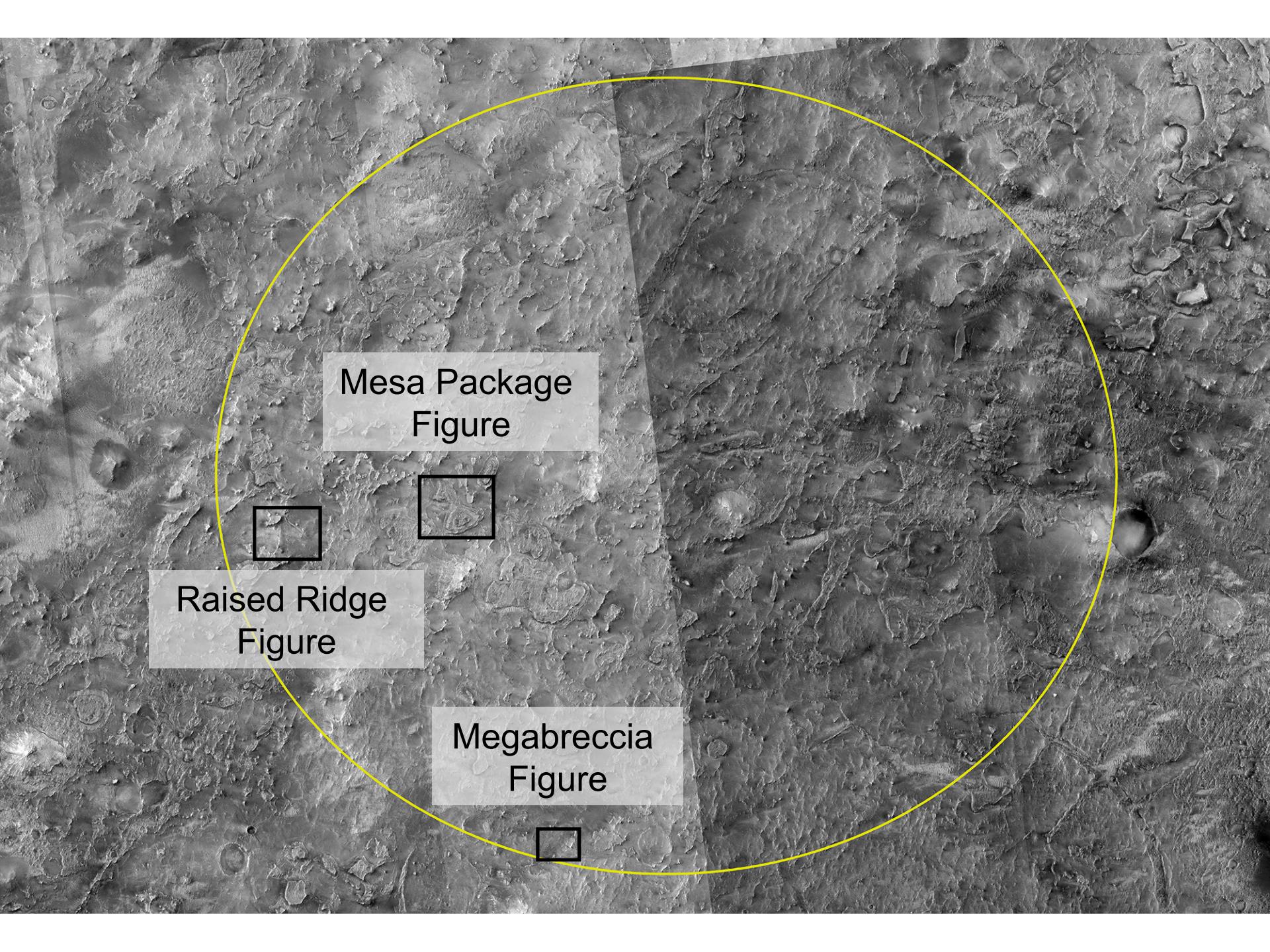
Ehlmann and Mustard GRL 2013

Noachian Crust: Megabreccia



100 m

24



Mesa Package
Figure

Raised Ridge
Figure

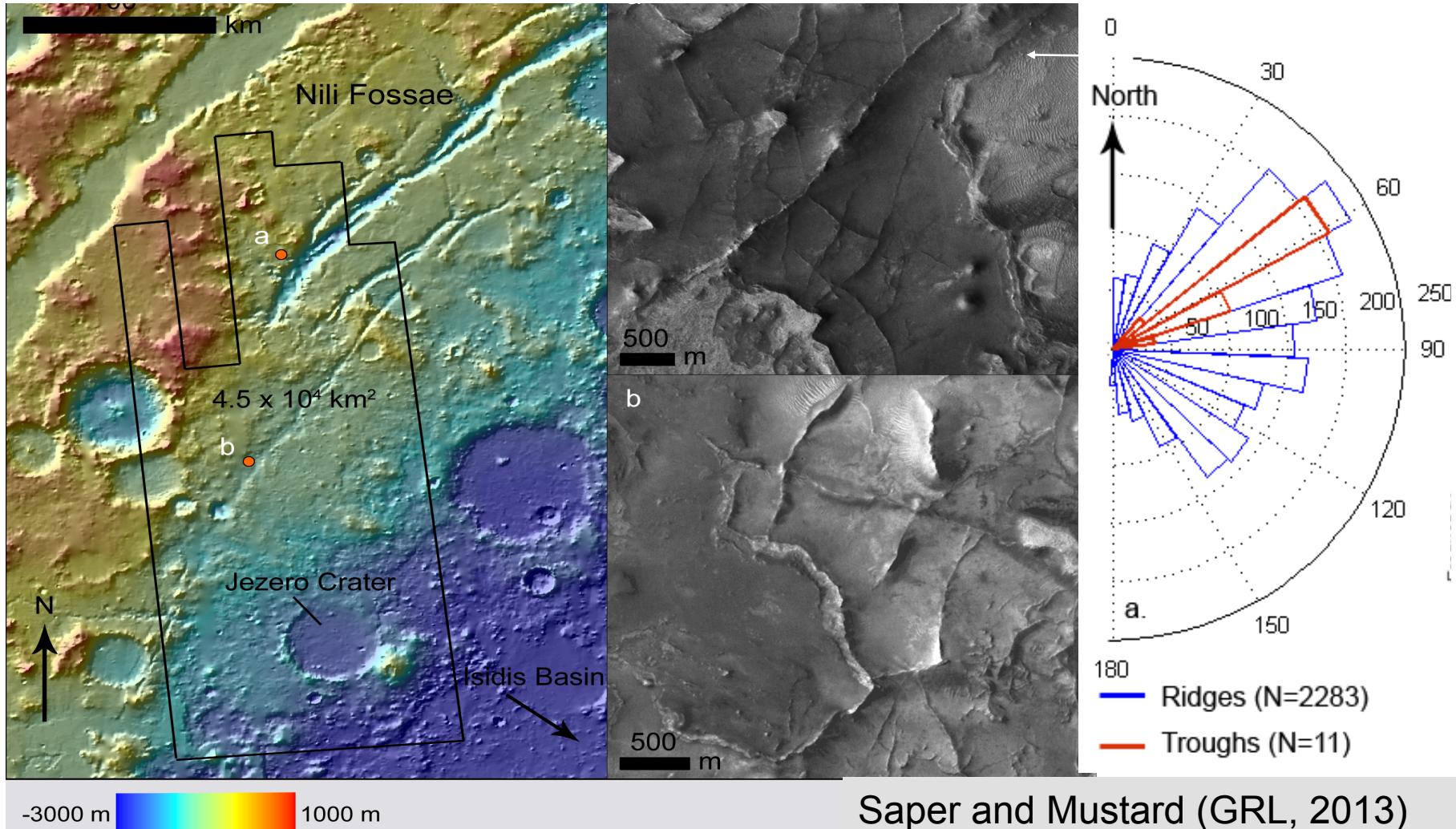
Megabreccia
Figure

Widespread ridges in the Noachian crustal unit, 10s m wide, 100s m long

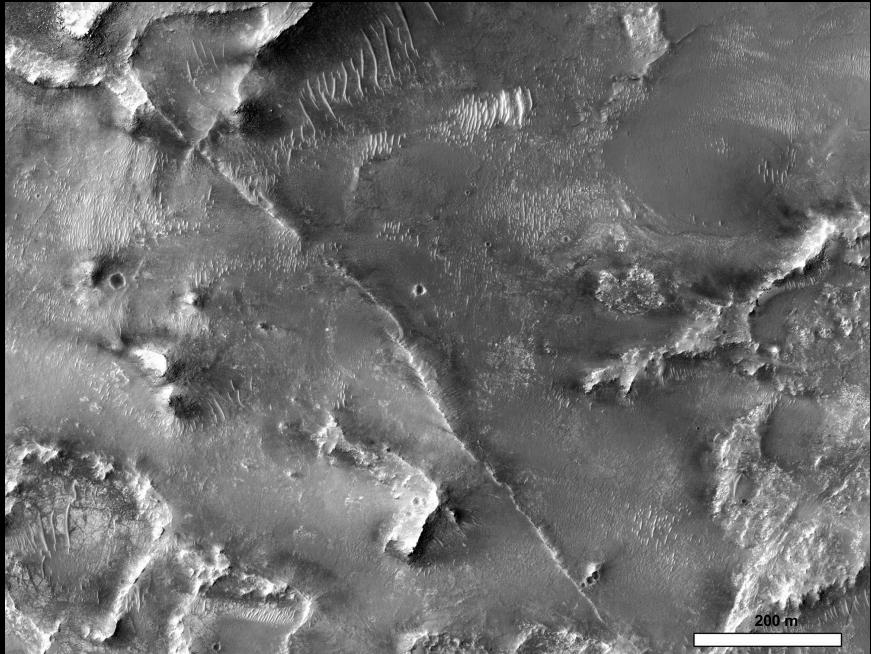
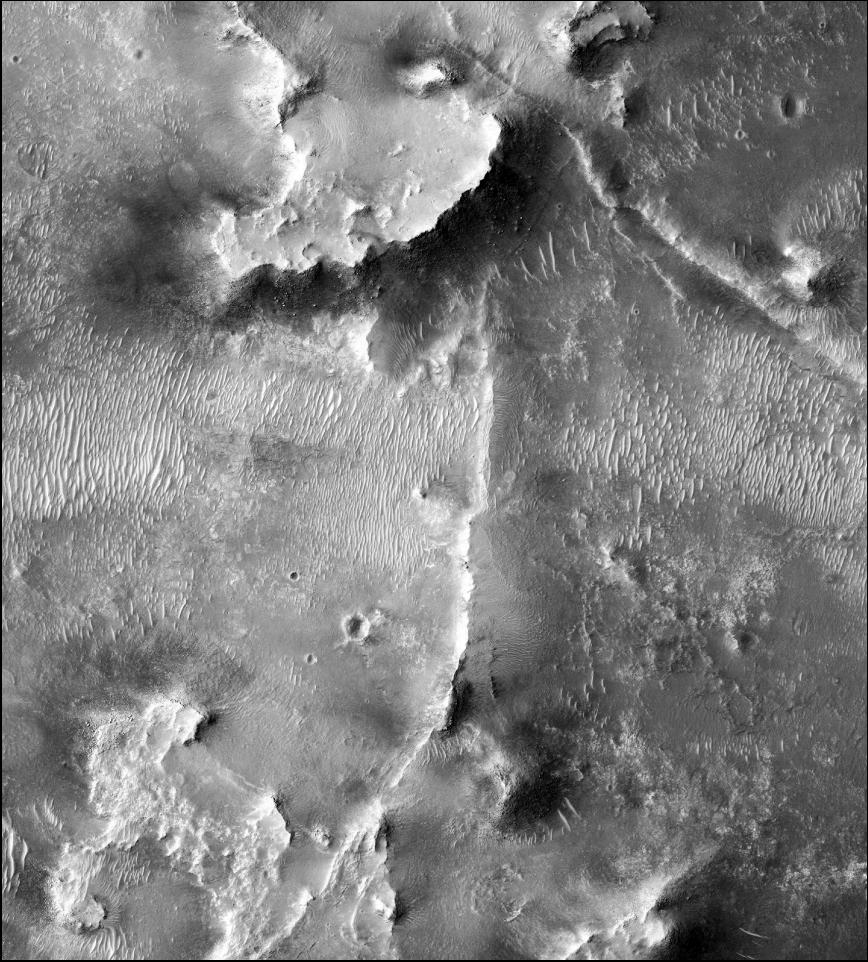
Morphology and Orientation of over 4000 Ridges suggest mineralized fracture zones

NE-SW orientation: Hydrothermal circulation in response to Isidis Impact?

Stratigraphically post-Isidis/pre-olivine/carbonate

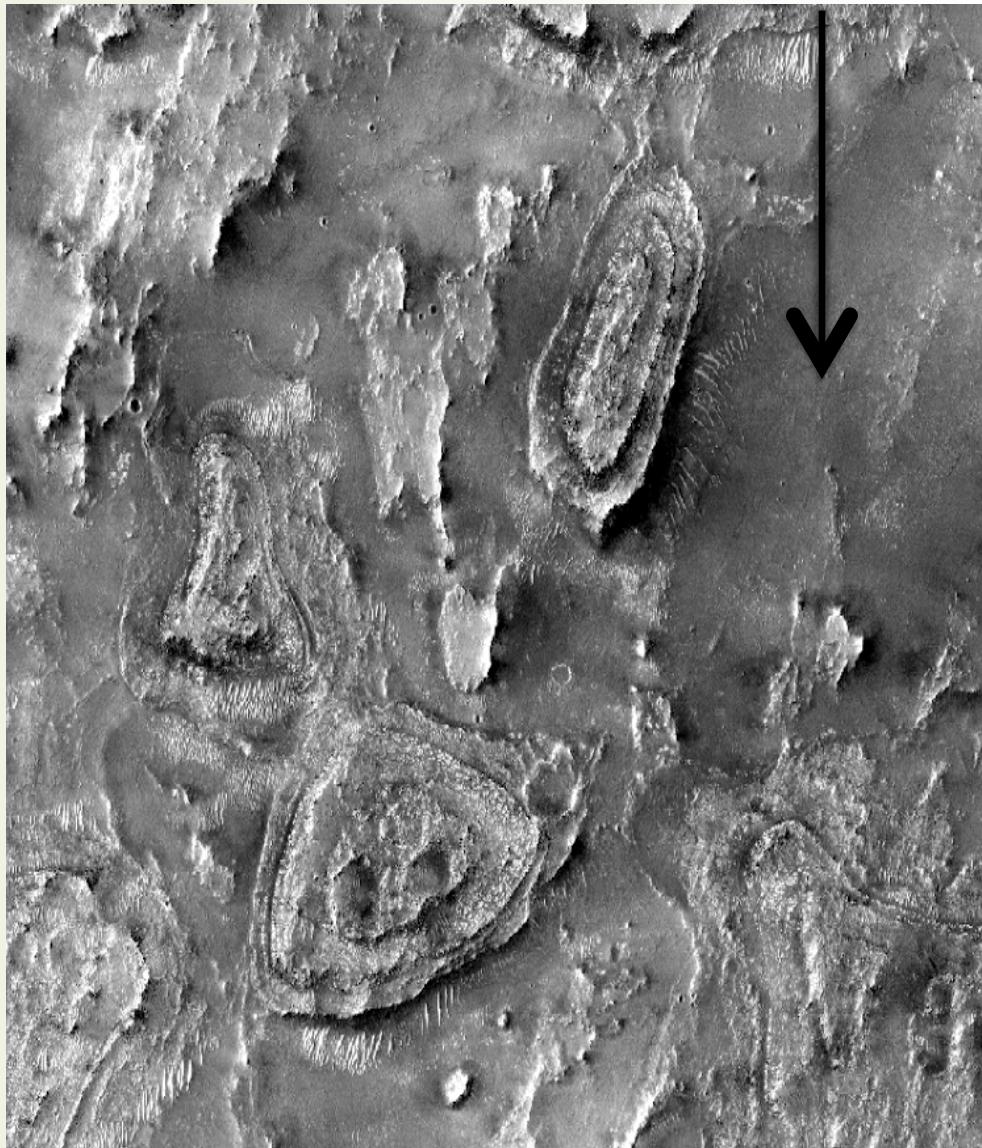


Noachian Basement: Erosionally Resistant Ridges of possible hydrothermal origin

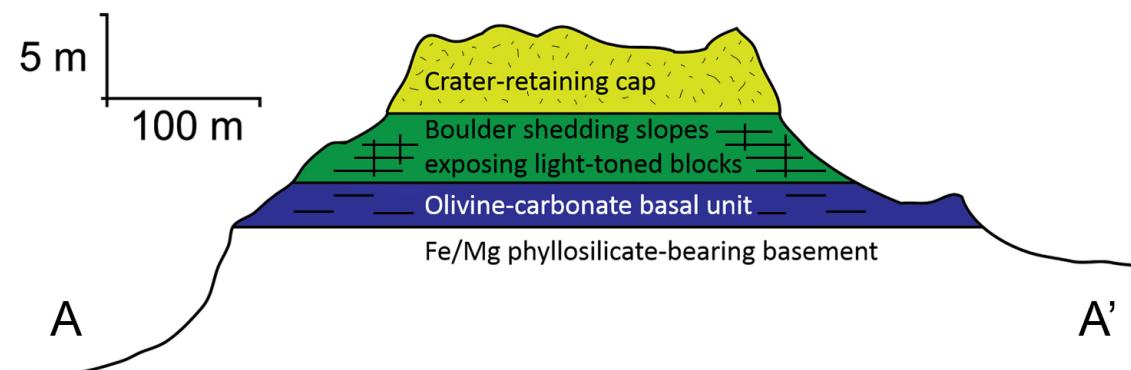
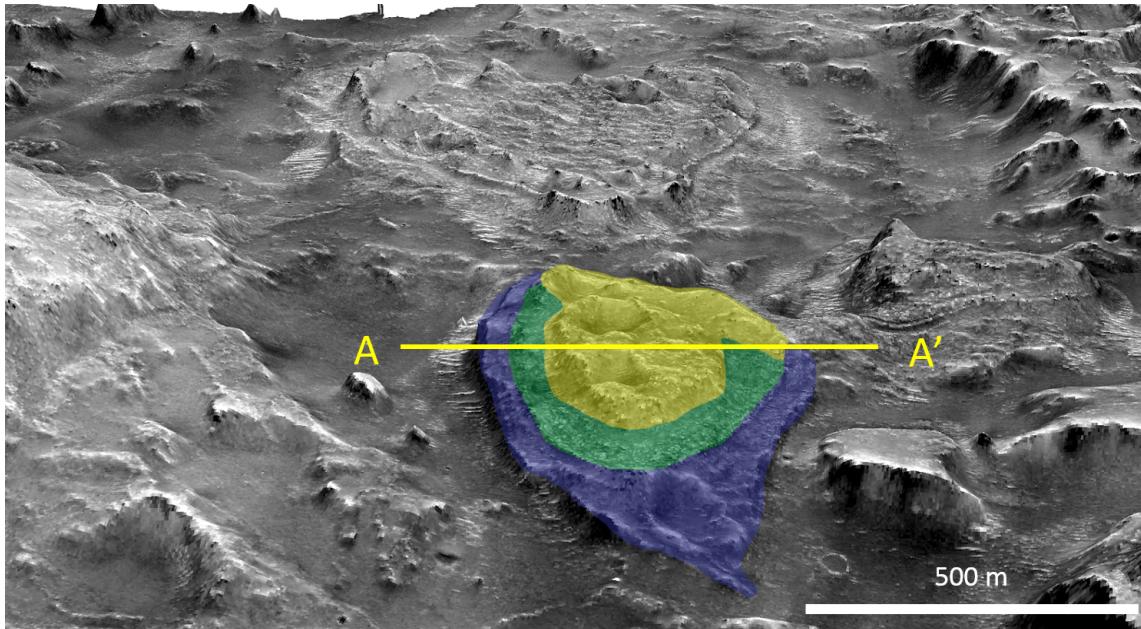


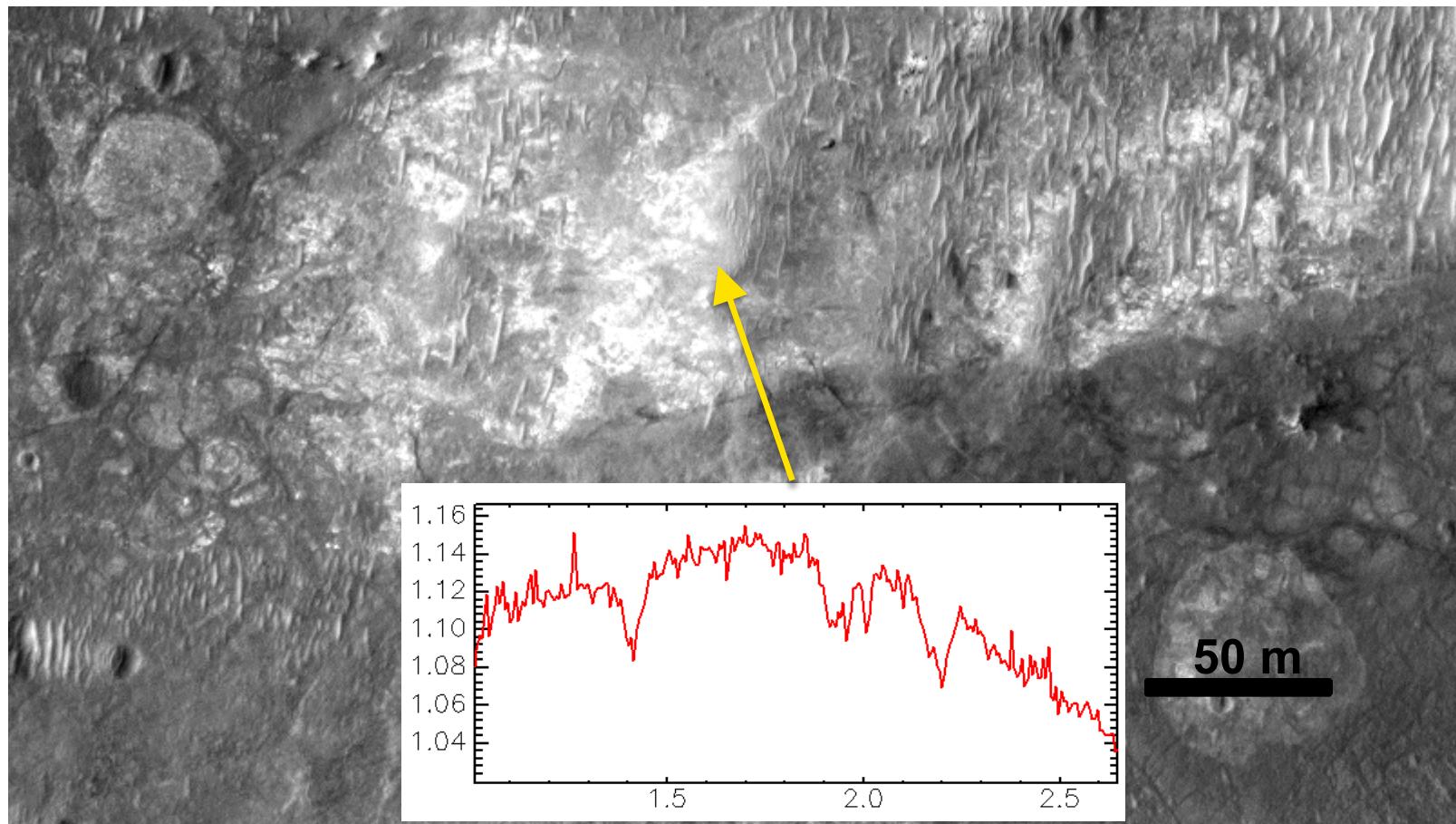
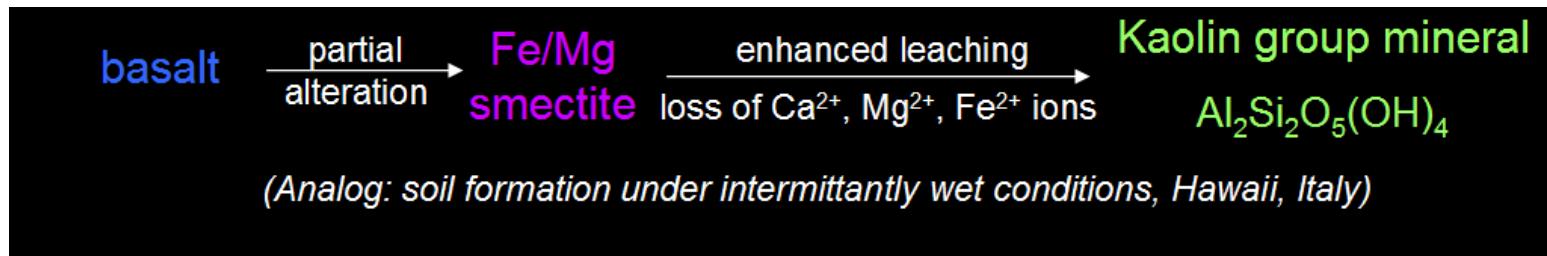
Mesa Forming Package

- Regional unit with three members
 - Crater retaining upper unit
 - Middle boulder shedding and slope forming unit
 - Lower unit that is banded, olivine bearing with variable carbonate
- Stratigraphically rests on basement of megabreccia and phyllosilicate
- Connected to many long, linear features with raised ridge borders, interiors of olivined-carbonate bearing materials
- Hypotheses:
 - Volcanic (Hamilton and Christensen, 2005; Tornabene et al., 2008)
 - Differentiated thick lavas
 - Sequence of volcanic flows from evolving source
 - Differentiated impact melt (Mustard et al., 2007; 2009)
- Olivine-bearing unit is a time-stratigraphic dateable unit!



Mesa Package Stratigraphy





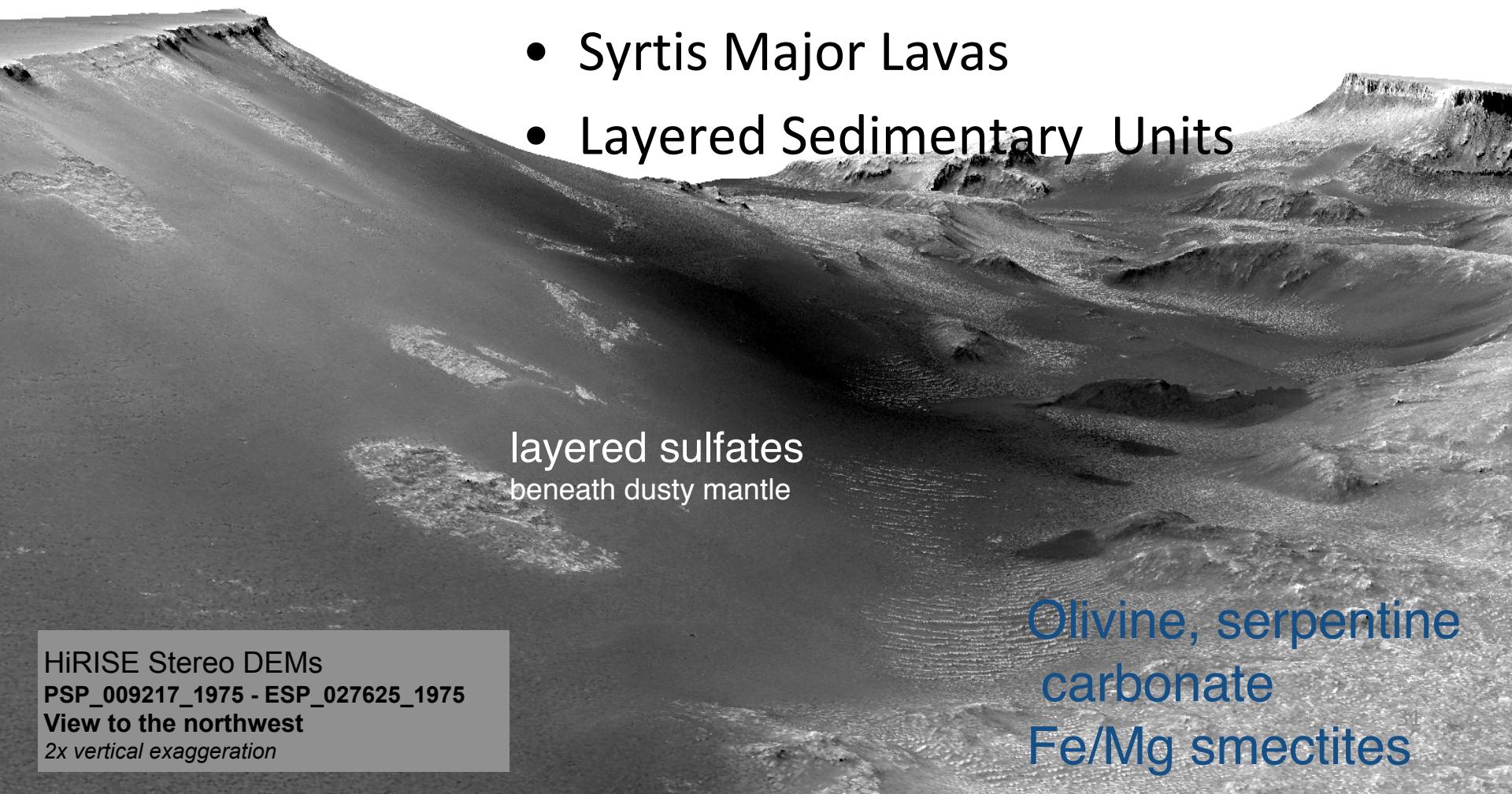
Kaolinitea-smectite alteration occurs where precursor rock is not olivine-rich (pyx, Fe/Mg smectite)

Science ROI 3

Major Resource ROI

- Abundant Polyhydrated Sulfate Deposits
- Syrtis Major Lavas
- Layered Sedimentary Units

Syrtis Major lavas

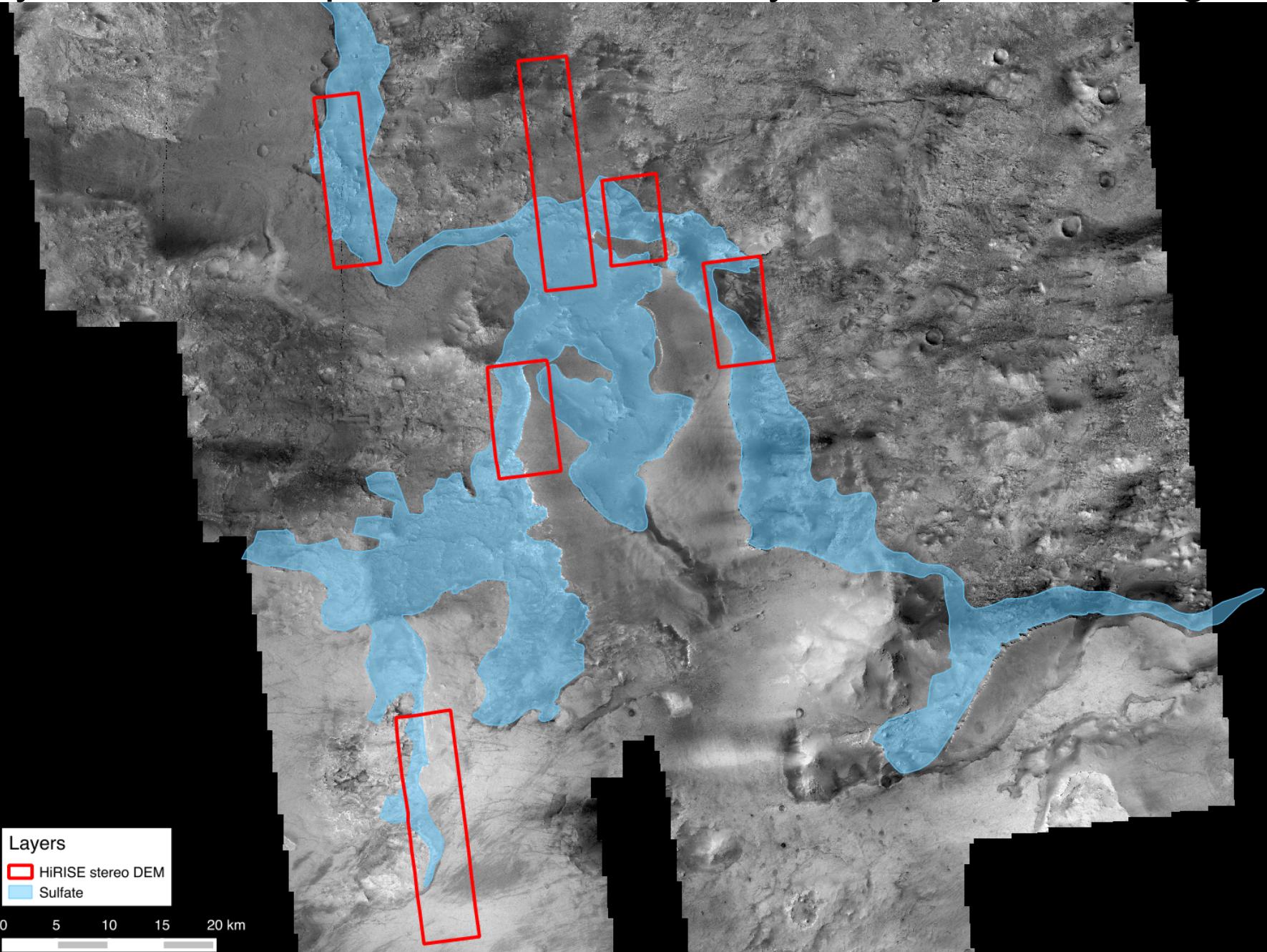


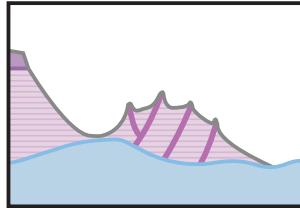
layered sulfates
beneath dusty mantle

HiRISE Stereo DEMs
PSP_009217_1975 - ESP_027625_1975
View to the northwest
2x vertical exaggeration

Olivine, serpentine
carbonate
Fe/Mg smectites

Layered sulfates preserved beneath Syrtis Major flow margin

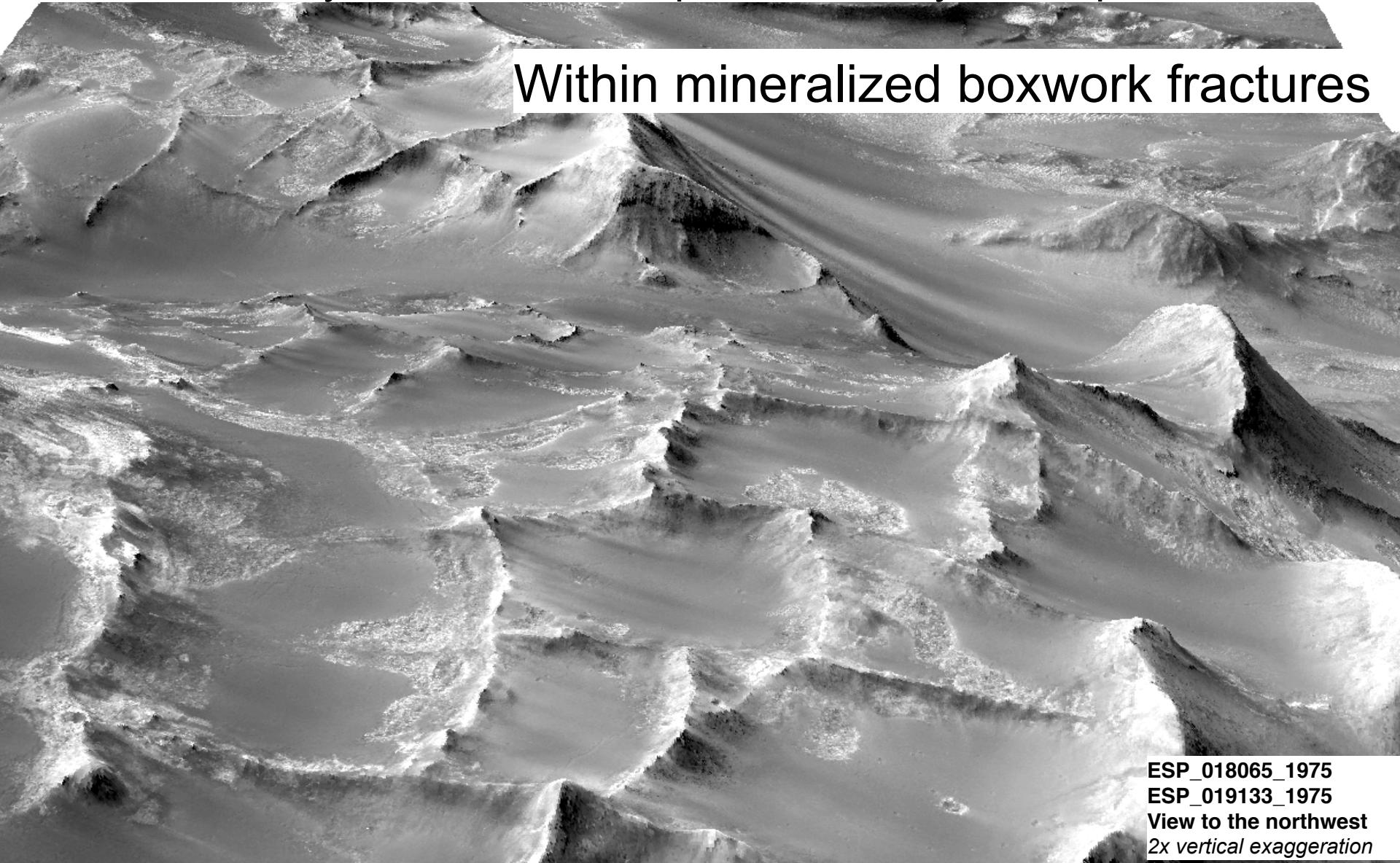




5. Differential erosion

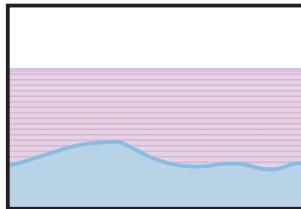
Layered sulfates are preserved only where protected

Within mineralized boxwork fractures

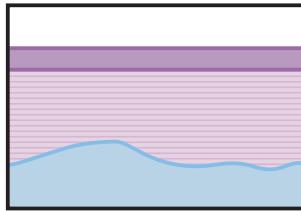


ESP_018065_1975
ESP_019133_1975
View to the northwest
2x vertical exaggeration

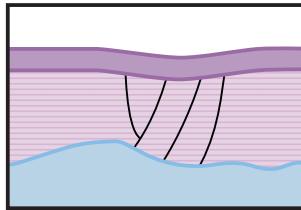
Layered sulfate chronology



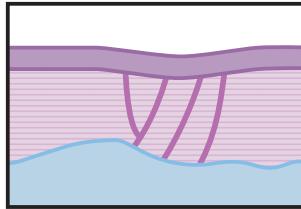
1. Deposition as flat-lying sediments



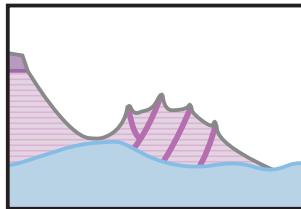
2. Burial by lava (\pm other sediments)



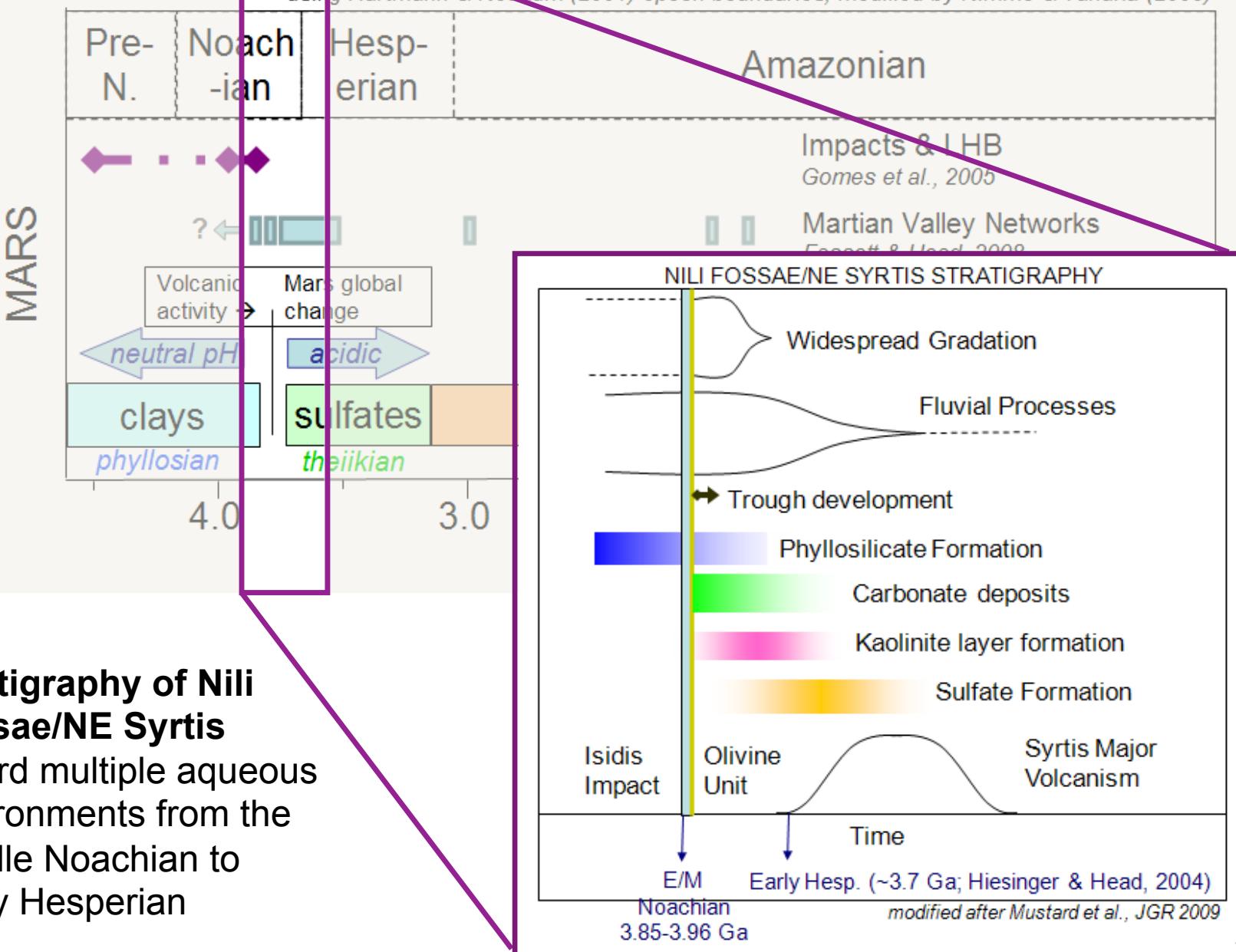
3. Diagenesis and volume-loss fracturing



4. Fluid mineralization along fractures



5. Differential erosion



Stratigraphy of Nili Fossae/NE Syrtis
 record multiple aqueous environments from the Middle Noachian to Early Hesperian

Science Conclusions

- Embarrassingly rich in science targets at the Noachian-Hesperian boundary
- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
 - early crustal: creation or distribution by impact
 - carbonate/serpentine: surface alteration or hydrothermal?
 - layered phyllosilicates (Al- over Fe/Mg): from leaching with surface hydrology?
 - (sedimentary?) acid sulfate formation
- A record of aqueous geochemistry preserved in-situ, in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting
- Key stratigraphies, dateable from Noachian to Hesperian eras
- Methane detected from ground based telescopes over Nili Fossae

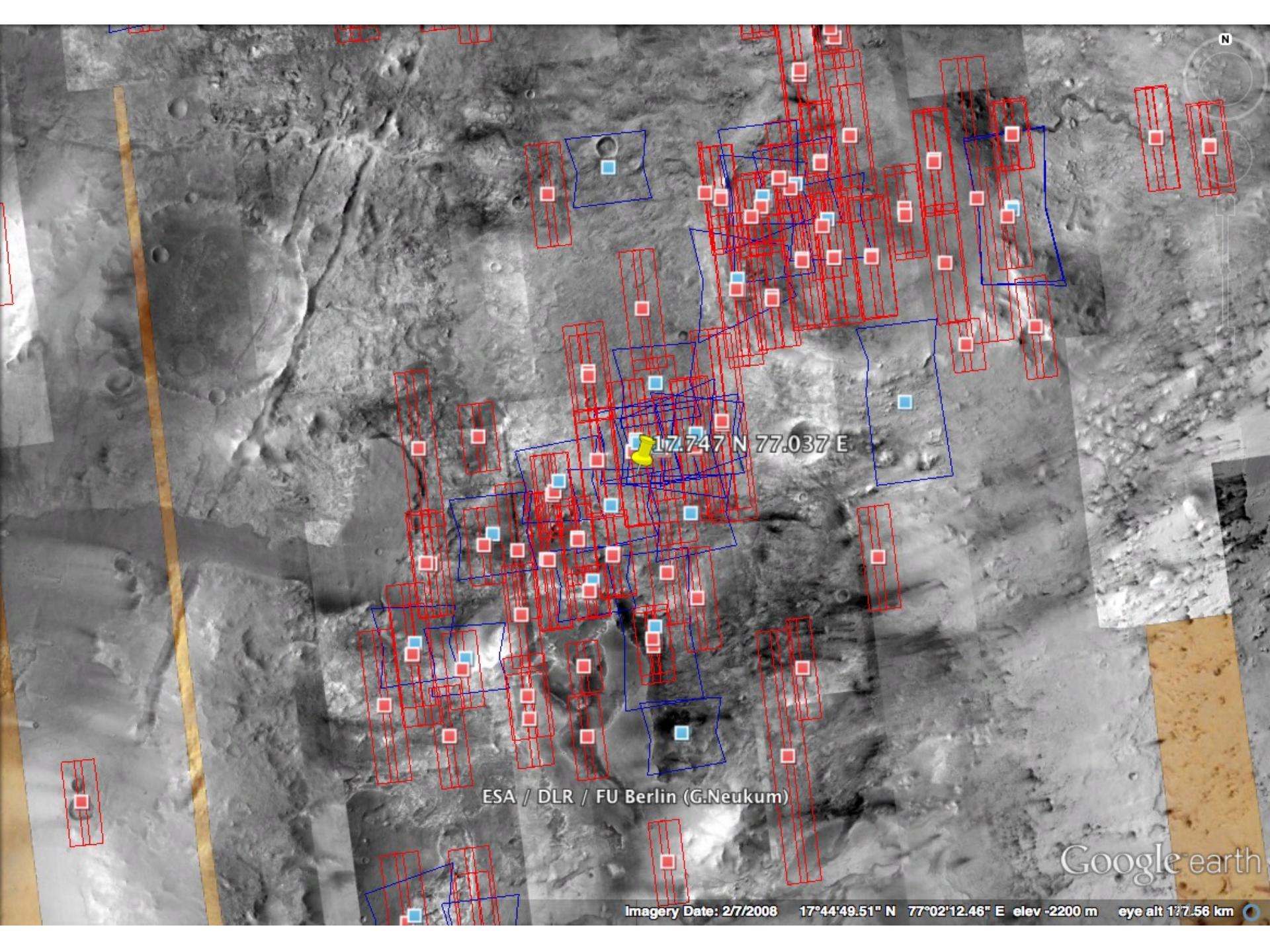
Resource Conclusions

- Resources are readily available in
 - Sulfate minerals (polyhydrated $\text{MgSO}_4 \cdot 4\text{H}_2\text{O}$, water resource and agricultural use)
 - Phyllosilicate minerals (smectite clays with exchangeable water)
 - Olivine-rich deposits
 - Kaolinite (ceramics)
 - Basaltic sands
 - Carbonate (concrete)

Mars 2020 Rubric

Site Factors							EZ SUM				
Science Site Criteria	Astrobio	Threshold	AND/OR	Potential for past habitability	SROI1	SROI2	SROI3	RROI1			
				Potential for present habitability/refugia							
	Qualifying			Potential for organic matter, w/ surface exposure	●	●	●	●	O		
	Atmospheric Science	Threshold		Noachian/Hesperian rocks w/ trapped atmospheric gases	●	●	●	●			
				Meteorological diversity in space and time	?	?	?	?			
		Qualifying		High likelihood of surface-atmosphere exchange	O	O	O	O	O		
				Amazonian subsurface or high-latitude ice or sediment							
				High likelihood of active trace gas sources	O	O	O	O	O		
	Geoscience	Threshold		Range of martian geologic time; datable surfaces	●	●	●	●			
				Evidence of aqueous processes	●	●	●	●			
				Potential for interpreting relative ages	●	●	●	●			
		Qualifying		Igneous Rocks tied to 1+ provinces or different times	●	●	●	●			
				Near-surface ice, glacial or permafrost							
				Noachian or pre-Noachian bedrock units	●	●	●	●			
				Outcrops with remnant magnetization							
				Primary, secondary, and basin-forming impact deposits	●	●	●	●			
				Structural features with regional or global context	●	●	●	●			

Site Factors													
ISRU and Civil Engineering Criteria	Engineering		Meets First Order Criteria (Latitude, Elevation, Thermal Inertia)		SROI1	SROI2	SROI3	SROI(n)	RROI1	RROI2	RROI3	RROI(n)	EZ SUM
	Water Resource	Threshold	AND / OR	Potential for ice or ice/regolith mix									
				Potential for hydrated minerals	M	M							
				Quantity for substantial production									
				Potential to be minable by highly automated systems									
				Located less than 3 km from processing equipment site									
				Located no more than 3 meters below the surface									
				Accessible by automated systems									
	Food Production	Civil Engineering	Qualifying	Potential for multiple sources of ice, ice/regolith mix and hydrated minerals									
				Distance to resource location can be >5 km									
				Route to resource location must be (plausibly) traversable									
	Metal/Silicon Resource	Threshold	Qualifying	~50 sq km region of flat and stable terrain with sparse rock distribution									
				1–10 km length scale: <10°									
				Located within 5 km of landing site location									
	Food Production	Civil Engineering	Qualifying	Located in the northern hemisphere									
				Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith									
				Utilitarian terrain features									
	Metal/Silicon Resource	Threshold	Qualifying	Low latitude									
				No local terrain feature(s) that could shadow light collection facilities									
				Access to water									
	Food Production	Civil Engineering	Qualifying	Access to dark, minimally altered basaltic sands									
				Potential for metal/silicon									
				Potential to be minable by highly automated systems									
	Metal/Silicon Resource	Threshold	Qualifying	Located less than 3 km from processing equipment site									
				Located no more than 3 meters below the surface									
				Accessible by automated systems									
	Food Production	Civil Engineering	Qualifying	Potential for multiple sources of metals/silicon									
				Distance to resource location can be >5 km									
				Route to resource location must be (plausibly) traversable									

N

ESA / DLR / FU Berlin (G.Neukum)

Imagery Date: 2/7/2008 17°44'49.51" N 77°02'12.46" E elev -2200 m eye alt 177.56 km

Google earth

Backup And Extras

4 Unprioritized ROI's

Landing Site and Engineering Constraints

- Target-rich in ellipse science; go-to traverses Noachian to Hesperian
- Key hypotheses addressed in the ellipse with M2020 measurements and caching

Center Coordinates	<ul style="list-style-type: none">• 17.84°N 77.15° W
Elevation	<ul style="list-style-type: none">• -2000 m WRT MOLA geoid
Prime Science and/or Sampling Targets	<ul style="list-style-type: none">• Olivine-carbonate assemblage• Isidis (?) megabreccia with phyllosilicate and unaltered igneous outcrops• Layered kaolinitized-bearing capping stratigraphy• Mineralized fracture zones• Hesperian-aged Sulfate stratigraphy• Hesperian Syrtis Major volcanics (lowest priority)
Distance of Science and/or sampling targets from Ellipse Center	<ul style="list-style-type: none">• In Ellipse targets are typically 3-5 km from the ellipse center (olivine-carbonate outcrops, megabreccia, mineralized fracture zones, layered stratigraphies)• Hesperian targets (sulfate stratigraphy and Syrtis volcanics) are outside the ellipse

Major Hypotheses to be Tested

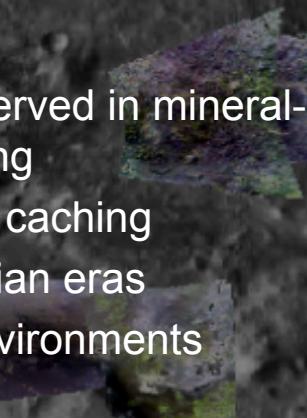
Olivine-bearing regional unit	<ul style="list-style-type: none">• Ultramafic volcanic emplaced post-Isidis• Ultramafic impact melt from Isidis that tapped the mantle
Olivine-Magnesite Mineral Assemblage	<ul style="list-style-type: none">• Near-surface weathering• Serpentinizing hydrothermal systems• Aqueous alteration in a metamorphic setting• Sedimentary/lacustrine deposits within ultramafic catchments
kaolinite-bearing capping stratigraphy:	<ul style="list-style-type: none">• Extensive leaching during a period of vertically integrated water cycle
Erosionally resistant ridges	<ul style="list-style-type: none">• Fracture zones mineralized with hydrothermal sediments• Volcanic dikes• Breccia dikes
Hesperian-aged Sulfate stratigraphy	<ul style="list-style-type: none">• Deposition as flat lying sediments• Extensive dewatering and mineralization of fractures
Hesperian Syrtis Major volcanics	<ul style="list-style-type: none">• Calibration of crater chronology, testing the formation mechanism (chemistry and mineralogy), validating remote sensing
Megabreccia with phyllosilicate and unaltered igneous outcrops	<ul style="list-style-type: none">• Phyllosilicate in megabreccia: Low-T, low water/rock ratio alteration in the shallow crust• Unaltered igneous outcrops<ul style="list-style-type: none">• Remnants of Mars primary crust• Noachian-aged low-Ca pyroxene lavas

Examples of the Strength of MSL Instrument To Address the Hypotheses

Olivine-bearing regional unit	<ul style="list-style-type: none">• Ultramafic volcanic emplaced post-Isidis• Ultramafic impact melt from Isidis that tapped the mantle• Mastcam-Z Context geology• Supercam: Reconnaissance and close-in major element chemistry LIBS VNIR mineral spectroscopy of ferrous igneous mineralogy to derive olivine Fe/Mg ratios Raman to determine context and close up mineralogy• PIXEL: Detailed elemental chemistry among mineral phases to resolve textures• SHERLOC: Discriminate detailed mineralogic associations
Olivine-Magnesite Mineral Assemblage	<ul style="list-style-type: none">• Supercam: Context and close-up aqueous mineralogy with VNIR Spectroscopy and RAMAN• PIXEL: Detailed mineralogy among minerals to determine assemblages• SHERLOC: Discriminate detailed mineralogic associations

Compelling Mars and Astrobiology Science

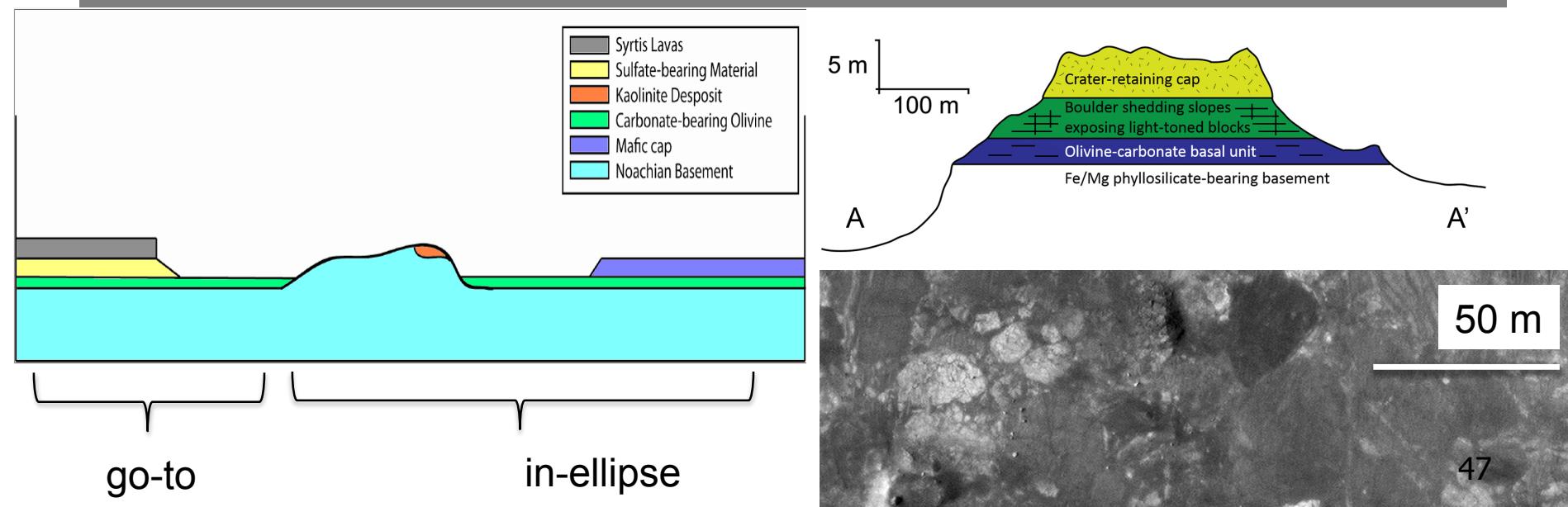
- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
 - early crustal: creation or distribution by impact? Phyllosilicate formation
 - carbonate/serpentine: surface alteration or hydrothermal?
 - layered phyllosilicates (Al- over Fe/Mg)
 - sedimentary sulfate formation
- A record of aqueous low-T geochemistry preserved in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting
- Well-suited for the M2020 measurements and caching
- Key stratigraphies from Noachian and Hesperian eras
- Hydrothermal, pedogenic and sedimentary environments
- Multiple igneous units of distinct age



Landing Site Factor	Mars 2020 Mission and Decadal Priority Science Factors																							
	Environmental Setting for Biosignature Preservation and Taphonomy of Organics					Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages							Type 2 Samples: Igneous		Context: Martian History Sampled, Timing Constraints									
	Deltaic or Lacustrine (perennial)	Lacustrine (evaporitic)	Hydrothermal (<100°C) surface	Hydrothermal (<100°C) subsurface	Pedogenic	Fluvial/Alluvial	No diagenetic overprinting	Recent exposure	Crustal phyllosilicates	Sedimentary clays	Al clays in stratigraphy	Carbonate units	Chloride sediments	Sulfate sediments	Acid sulfate units	Silica deposits	Ferric Ox./Ferrous clays	Igneous unit (e.g. lava flow, pyroclastic, intrusive)	2nd Igneous unit	Pre- or Early-Noachian Megabreccia	Oldest stratigraphic constraint	Youngest stratigraphic constraint	Stratigraphy of units well-defined	Dateable surface, volcanic (unmodified crater SFD)
NE SYRTIS			~	~	●	○	~	●	●		●	●	○	○			●	○	●	LN	H	●	●	

NE Syrtis: Rich diversity of Habitability

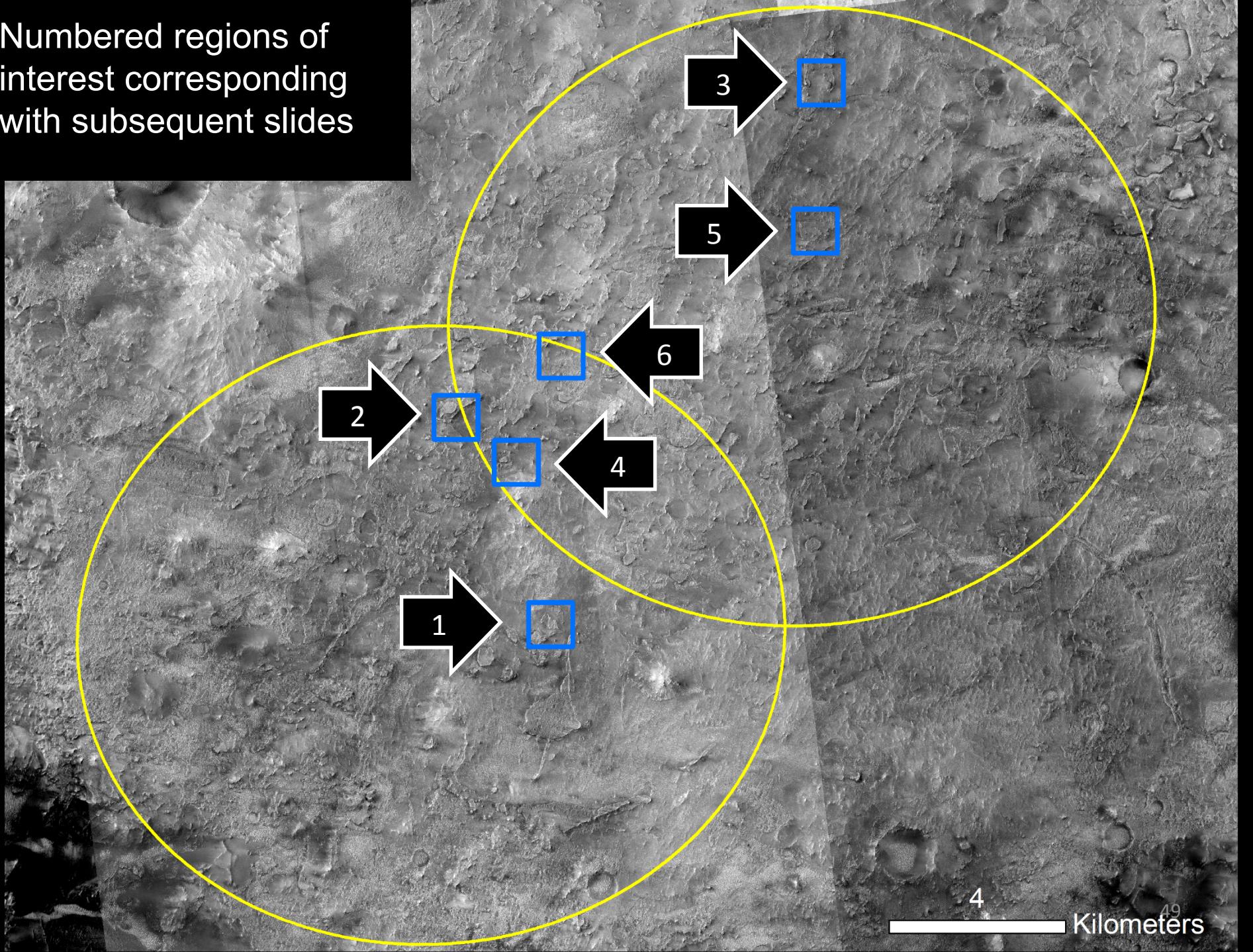
- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
 - early crustal megabreccia: Phyllosilicate formation; deep biosphere, Isidis basin formation, primary crust
 - carbonate/serpentine: surface alteration or hydrothermal?
 - layered phyllosilicates (Al- over Fe/Mg)
 - sedimentary sulfate formation
- A record of aqueous low-T geochemistry preserved in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting
- Well-suited for the M2020 measurements and caching
- Key stratigraphies from Noachian and Hesperian eras
- Hydrothermal, pedogenic and sedimentary environments
- Multiple igneous units of distinct age



Regions of Interest

- Target rich landing ellipse provides innumerable targets of interest, and we show 4 here
- Easily accomplish 90% of landing site goals in these 3 ROIs

Numbered regions of interest corresponding with subsequent slides

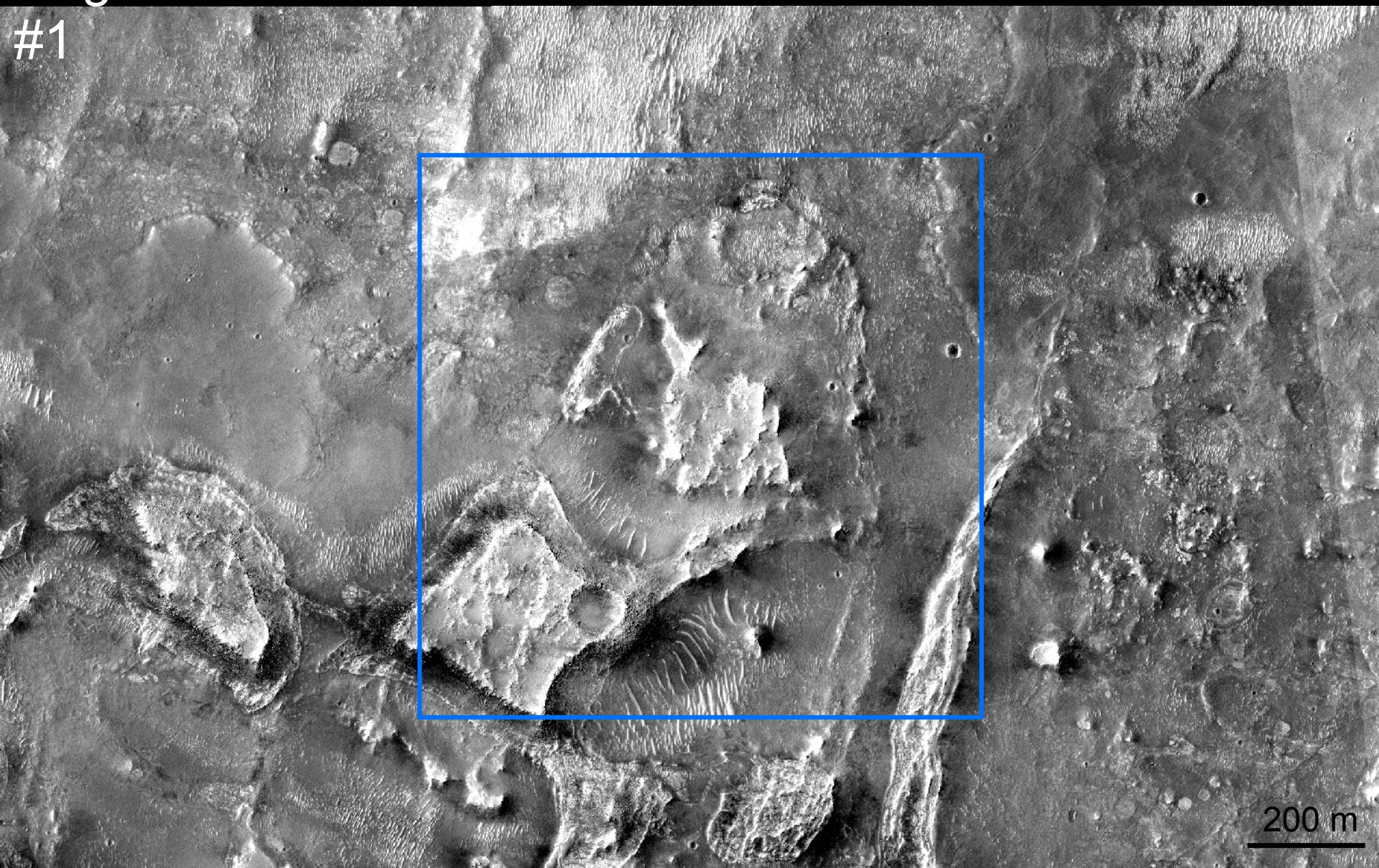


4

Kilometers

Region of Interest

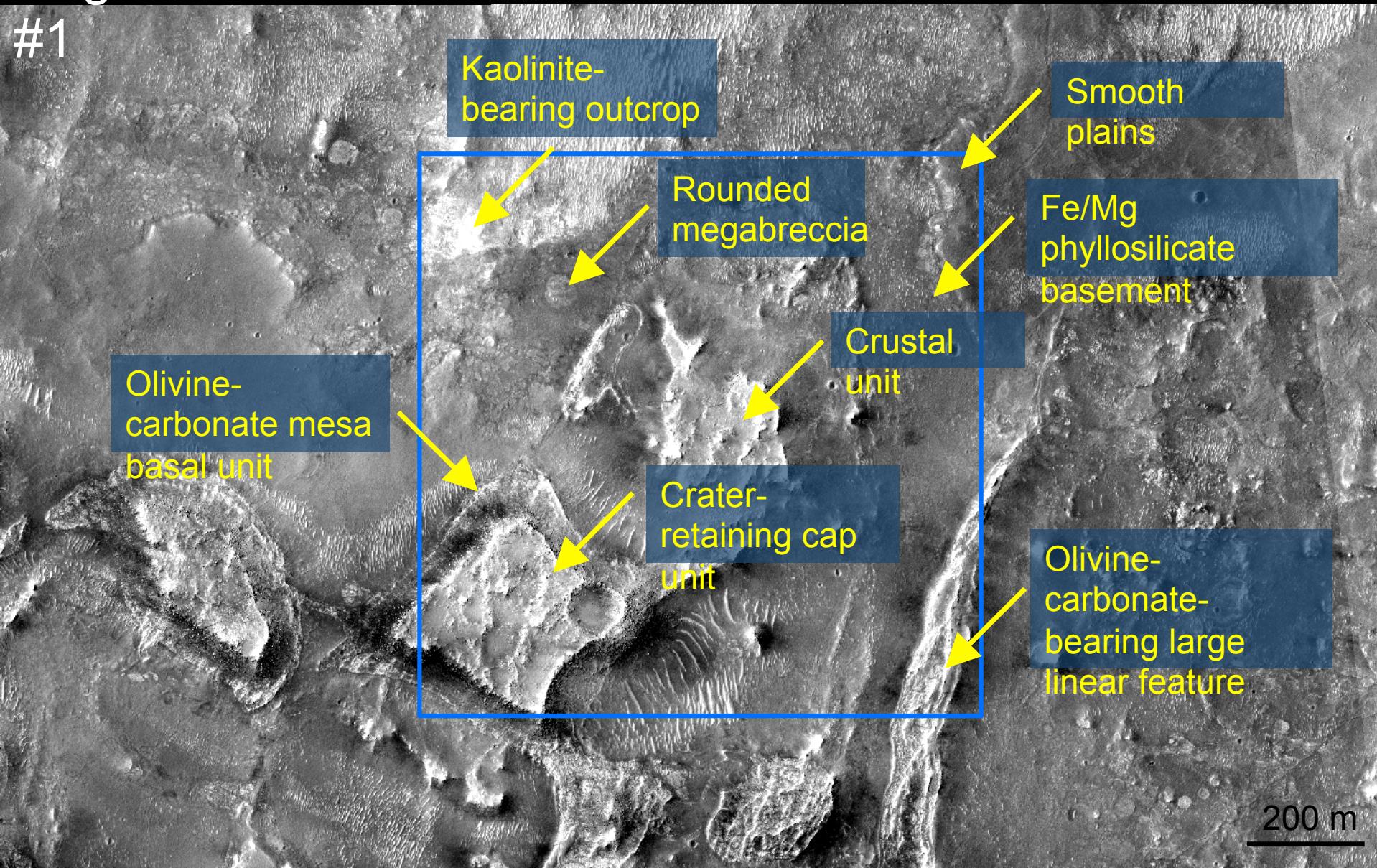
#1



200 m

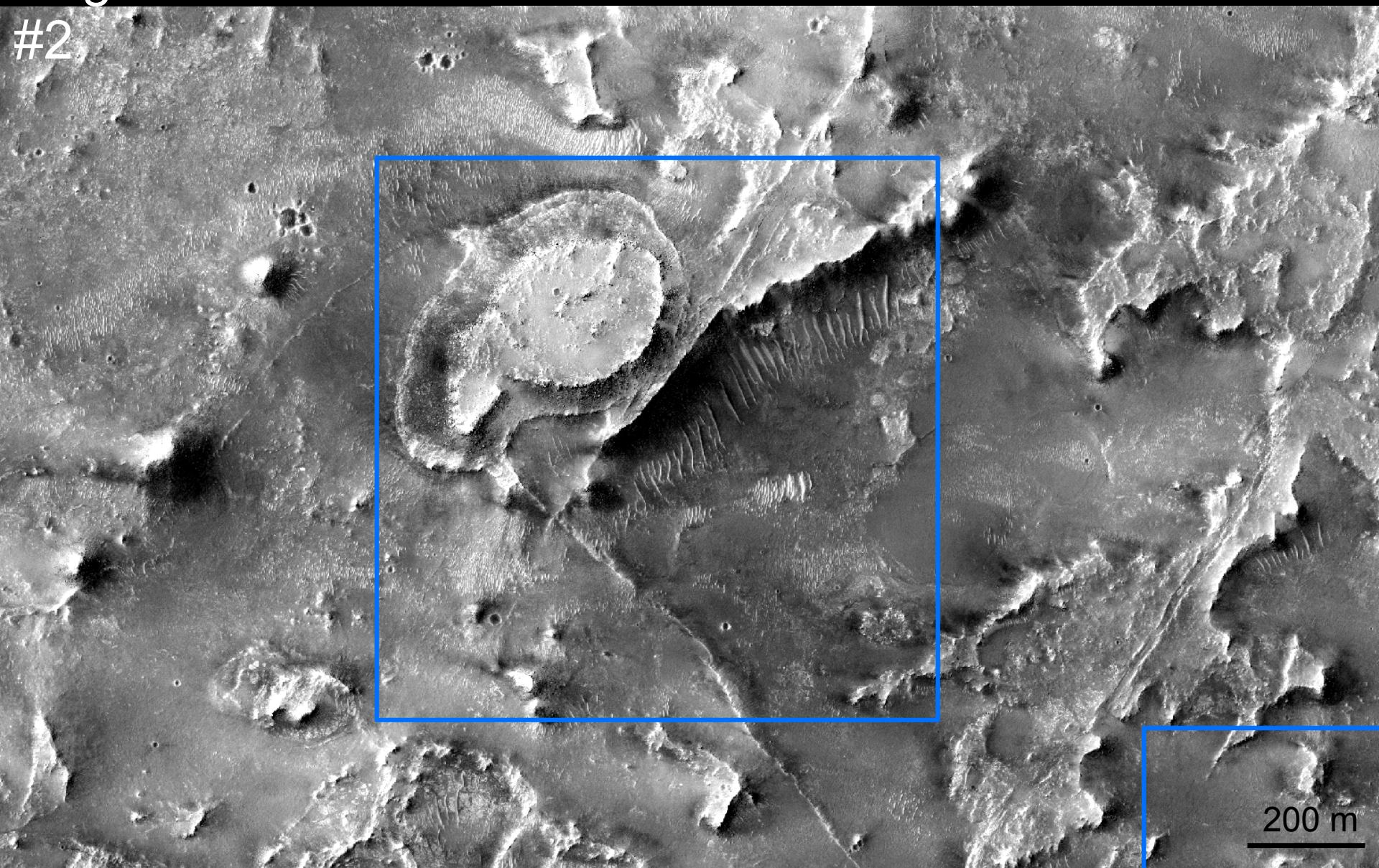
Region of Interest

#1



Region of Interest

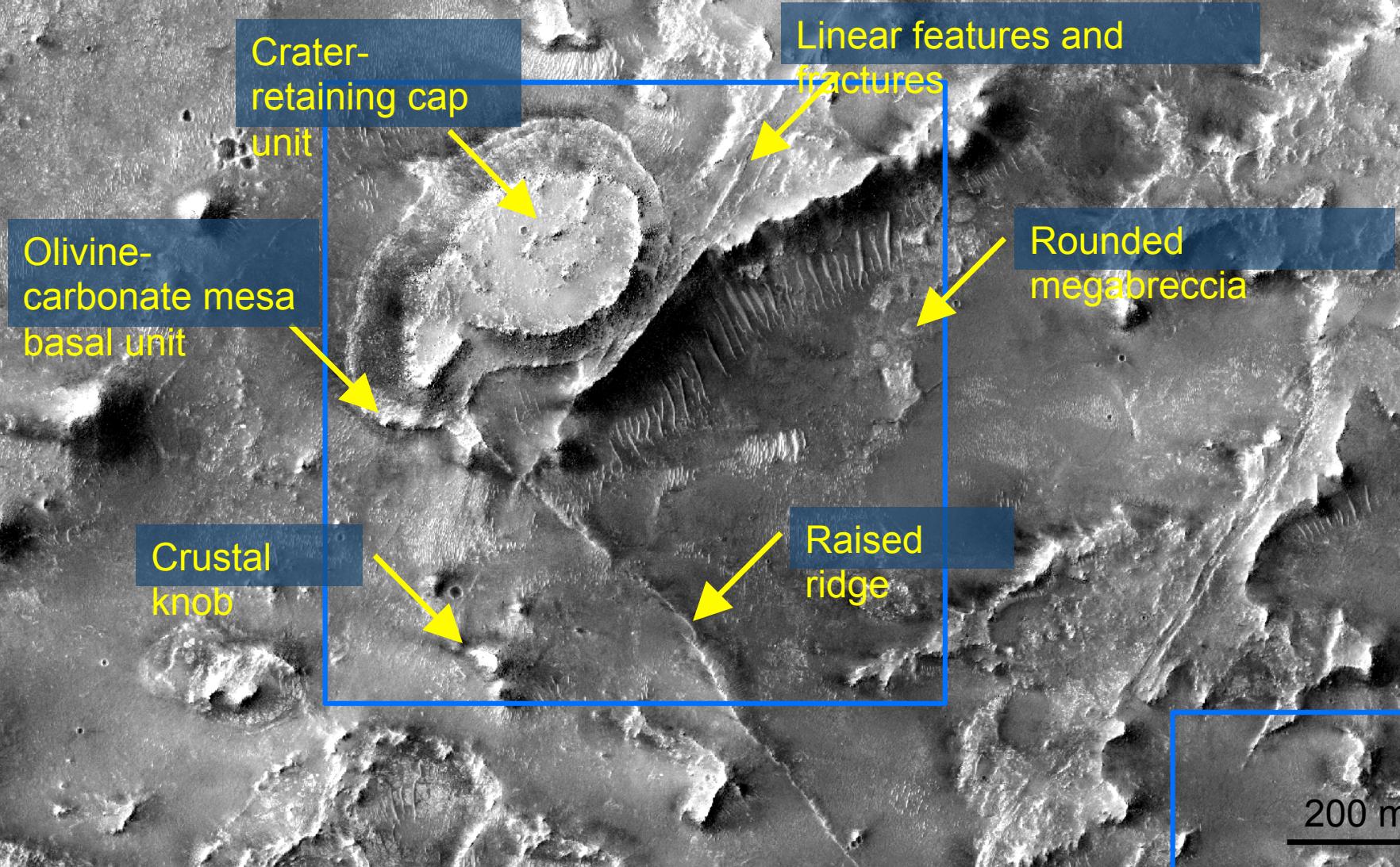
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200 m

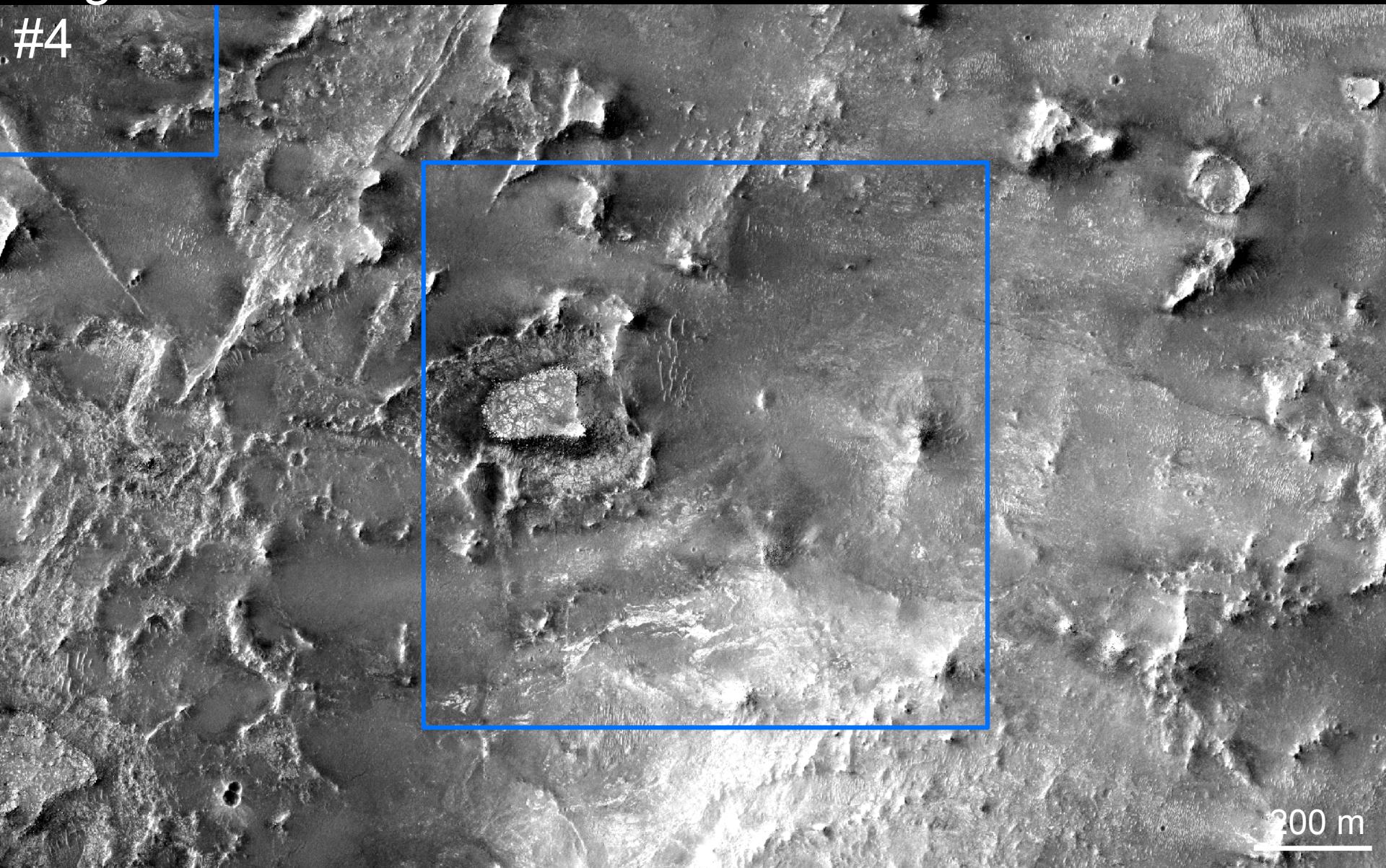
Region of Interest

#2



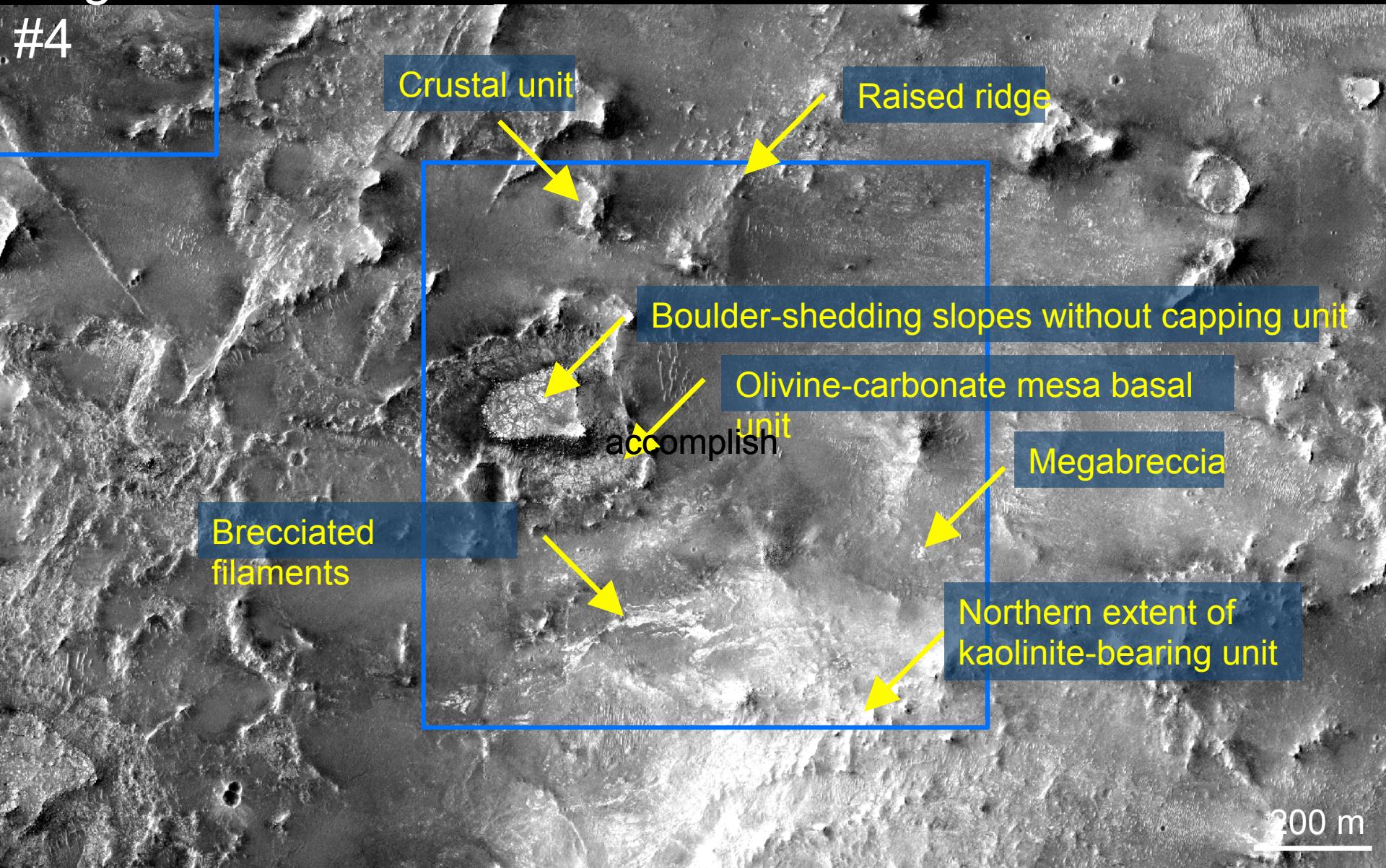
Region of Interest

#4



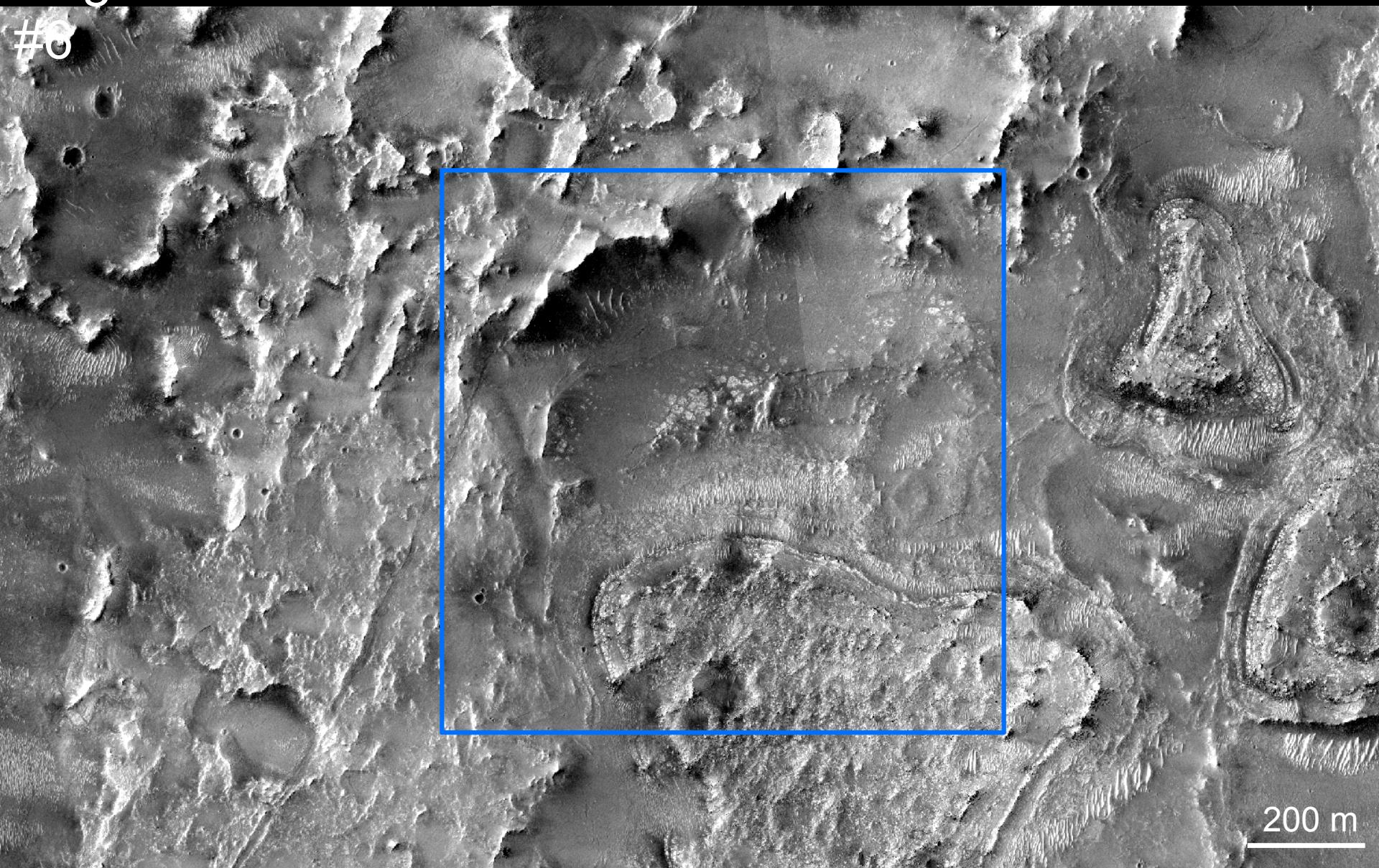
Region of Interest

#4



Region of Interest

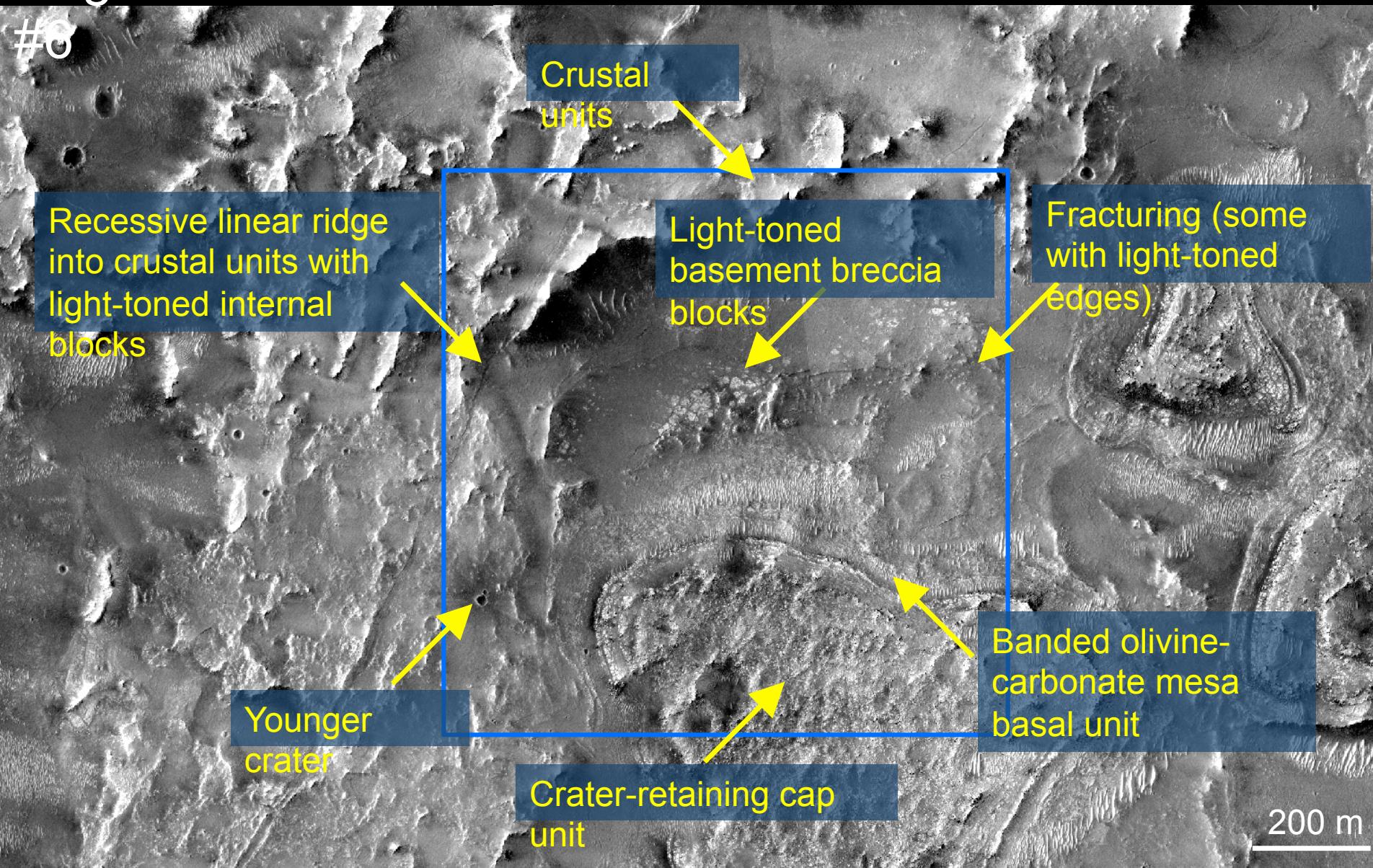
#3



200 m

Region of Interest

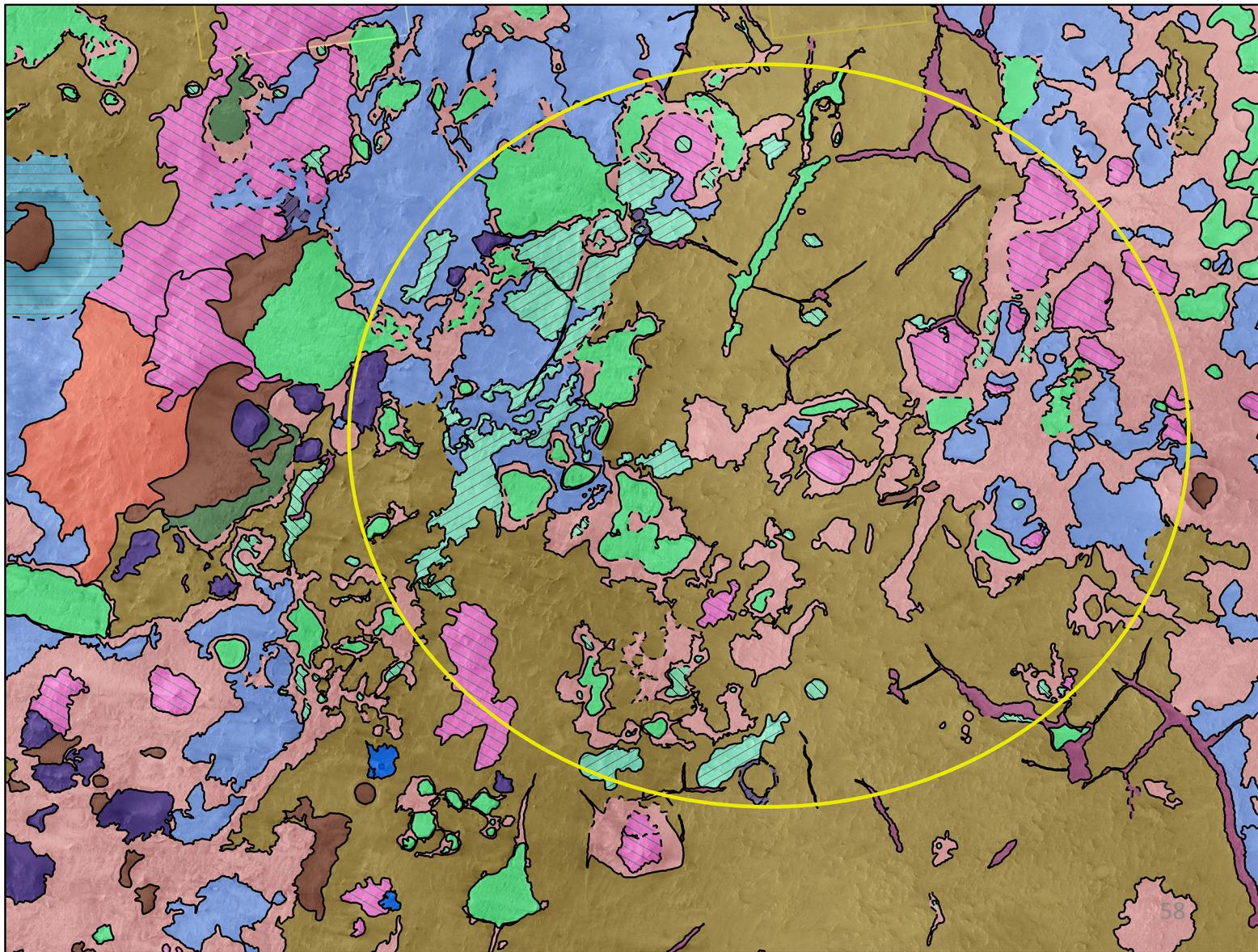
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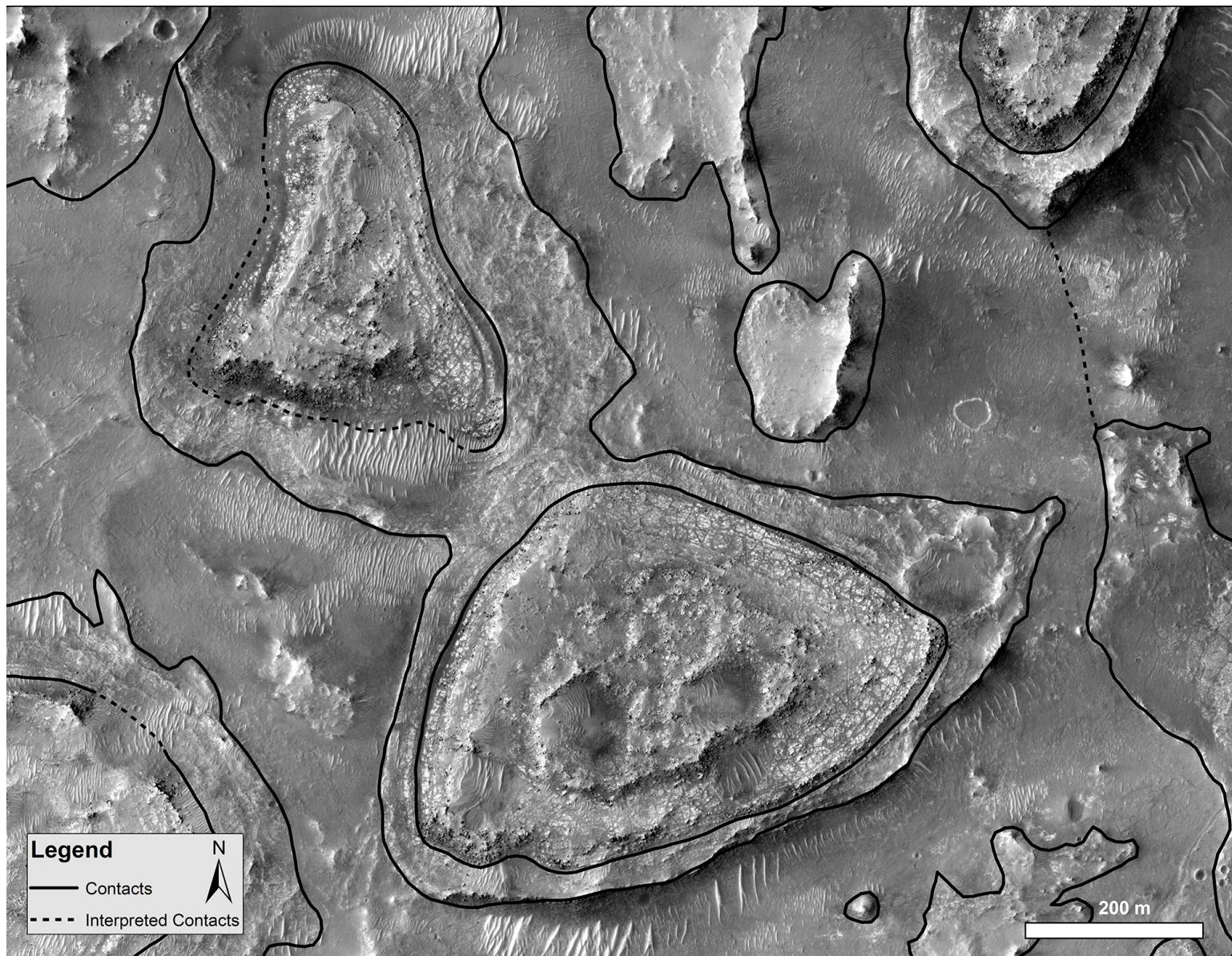


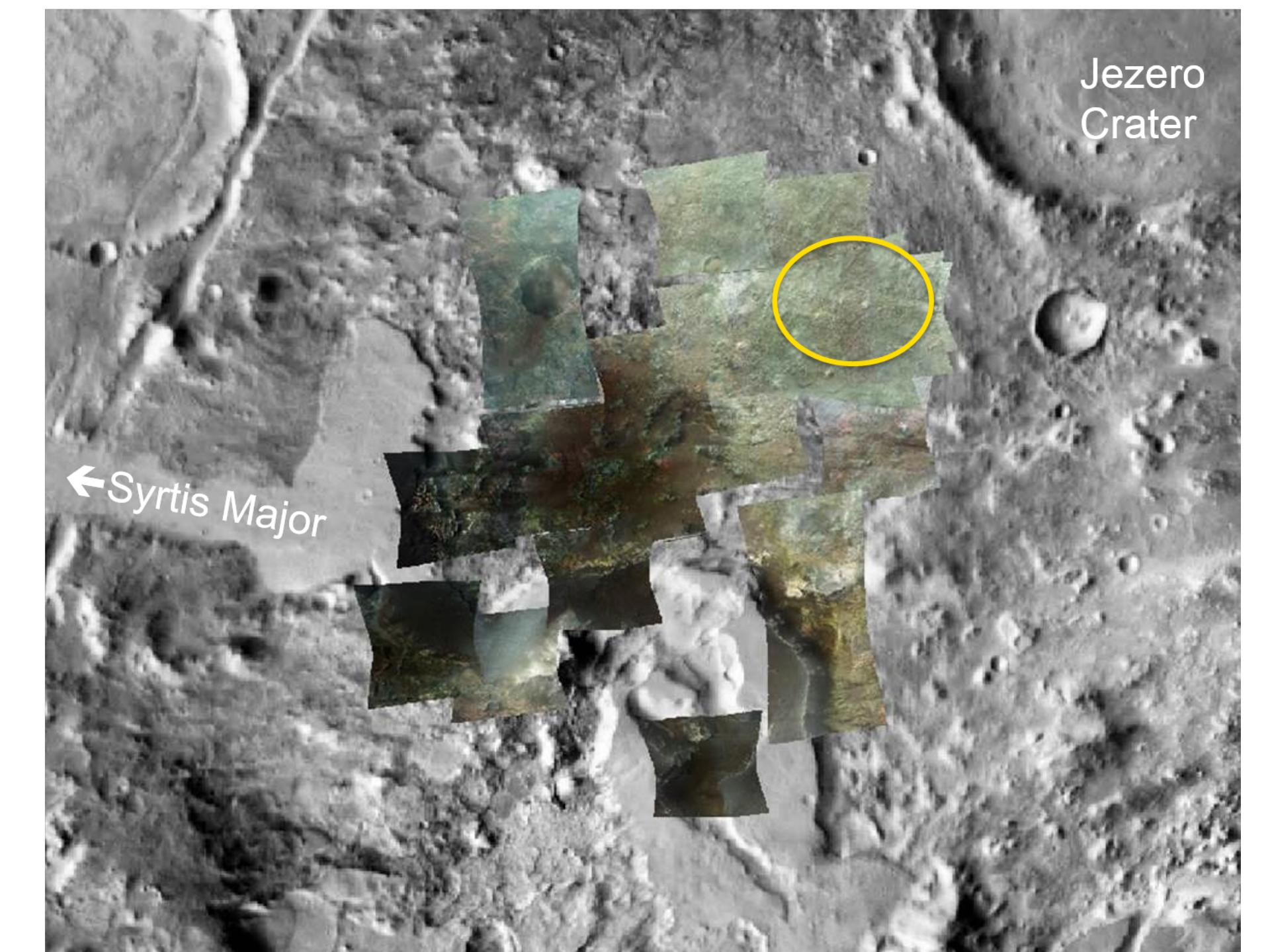
Mapping Northeast Syrtis Major



4 km





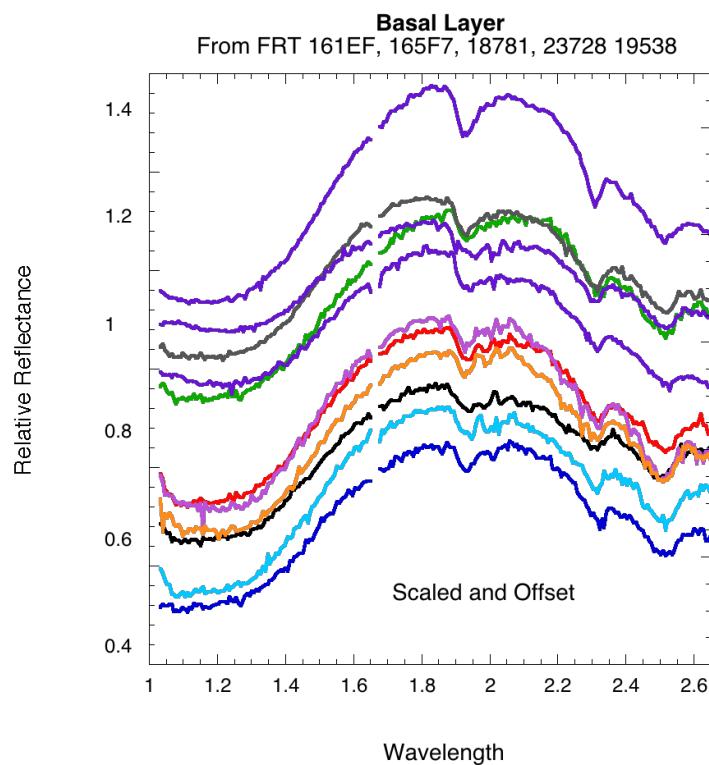
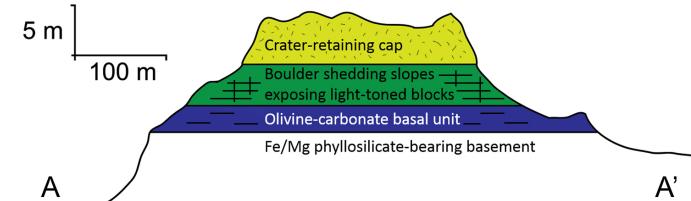


Jezero
Crater

←*Syrtis Major*

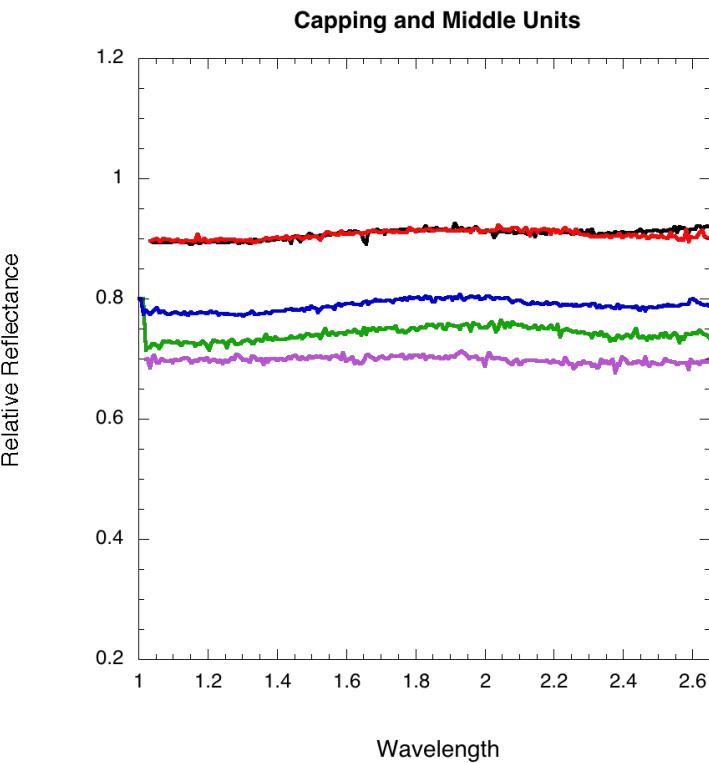
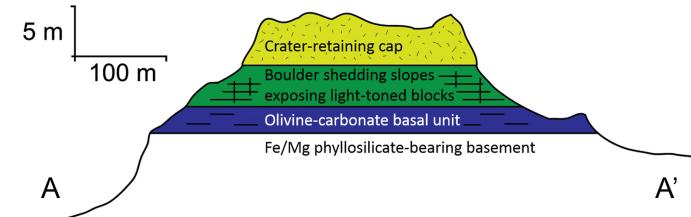
Spectroscopy/Mineralogy

- Olivine-rich basaltic composition (Mustard et al., 2007; Edwards and Ehlmann 2015)
- Partially carbonated (Ehlmann and Mustard, 2012)
- Broad 1-1.6 μm absorption
- Paired 2.3 and 2.5 μm band indicative of carbonate
- 1.9 μm band of variable strength
- No 1.4 μm band
- Variable presence of a 2.38-2.39 band
 - Mixing with Fe-Mg phyllosilicate (Ehlmann et al., 2008, 2009)
 - Mixing with Talc (Viviano et al., 2013)



Spectroscopy/Mineralogy

- Capping and Middle units show weak mafic igneous absorptions near 1 and 2 μm
- Consistent with pyroxene and olivine, as modeled by Edwards and Ehlmann 2015
- Capping and Middle units distinguished by morphology and texture



Carbonation of olivine-rich rocks

Hypotheses

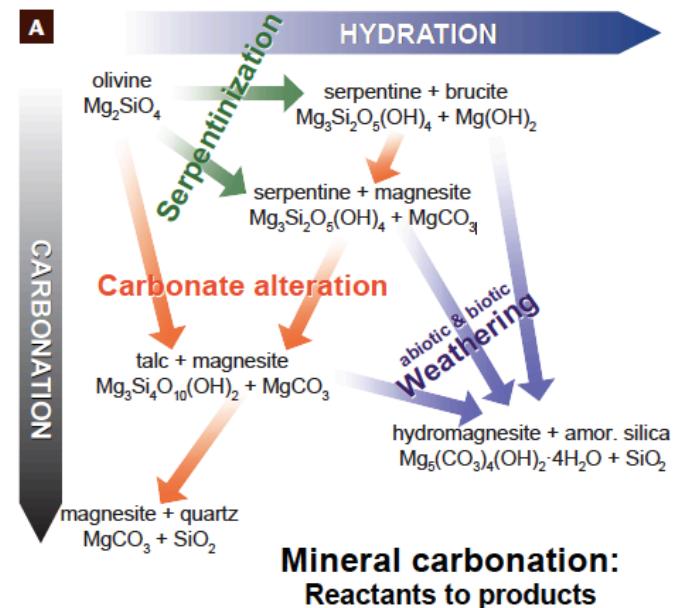
- 1) Water-rock interaction in the shallow subsurface at slightly elevated temperatures altered olivine to Mg-carbonate
- 2) Olivine-rich material, heated by impact or volcanic processes, emplaced on top of a water-bearing phyllosilicate rich unit initiated hydrothermal alteration along the contact
- 3) Olivine-rich rocks were weathered to carbonate at surface (cold) temperatures in a manner similar to olivine weathering of meteorites in Antarctica
- 4) Carbonate precipitated from shallow ephemeral lakes
- 5) Extended period of heat and water with burial leading to olivine-serpentine-talc-chlorite alteration pathway with carbonate from carbonation of serpentine (Brown et al., 2010; Viviano et al., 2013)

Unit of high value for environmental and astrobiological significance

Carbonation of Olivine

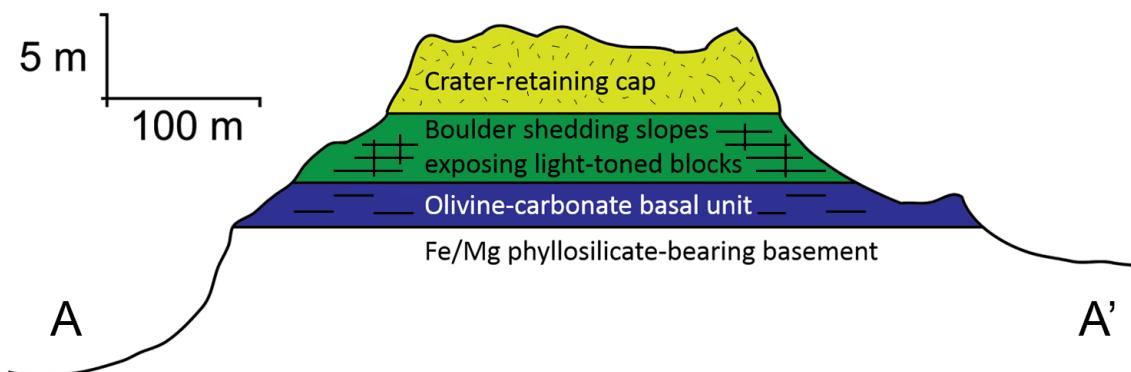
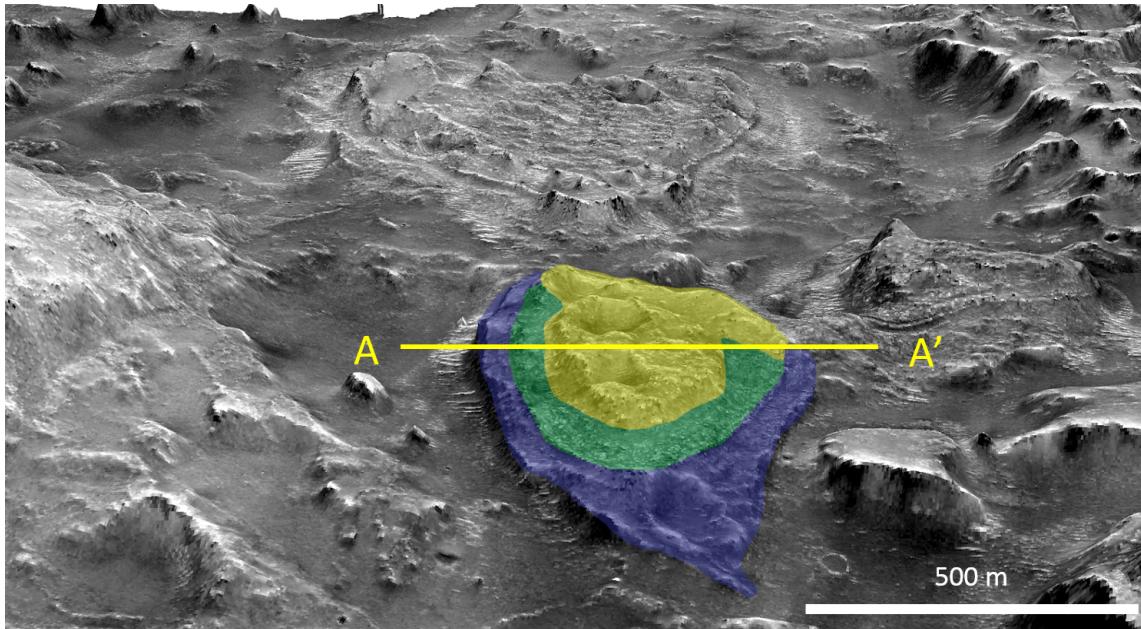


- Multiple reaction pathways with different intermediate products (e.g. talc, serpentine) depending on diverse environmental constraints
- The direct pathway, observed in Oman, is energetically favorable and consistent with the geologic observations
- Carbonation of olivine is enhanced by multicomponent basalt (Sissman et al., 2014)
- Significant liberation of SiO_2 : what is its fate?
- Assemblages, texture and context critical input to hypothesis testing



Power et al. (2013) DOI: 10.2113/gselements.9.2.115

Mesa Package Stratigraphy



Noachian Crust: No samples...yet*

- Megabreccia uplifted and exposed by the Isidis Basin Forming event
 - Tap into Noachian rocks from the era of phyllosilicate formation:
 - Access to samples relevant to the deep biosphere:
 - Ancient, crystalline igneous crust:
 - Sample low-Ca pyroxene rich and other crystalline igneous rocks to constrain early crustal processes (Elkins-Tanton et al., 2005; 2012; Baratoux et al., 2011; Grott et al., 2013)
- Sample materials from the period during which Mars likely had
 - Magnetic field (Acuna et al., 1999),
 - Thicker atmosphere with different isotopic composition (Jakosky & Jones, 1997),
 - Pre-/during-the late heavy bombardment
- Highly relevant to the question "What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large impact play?"

Noachian Basement: In Ellipse Megabreccia

